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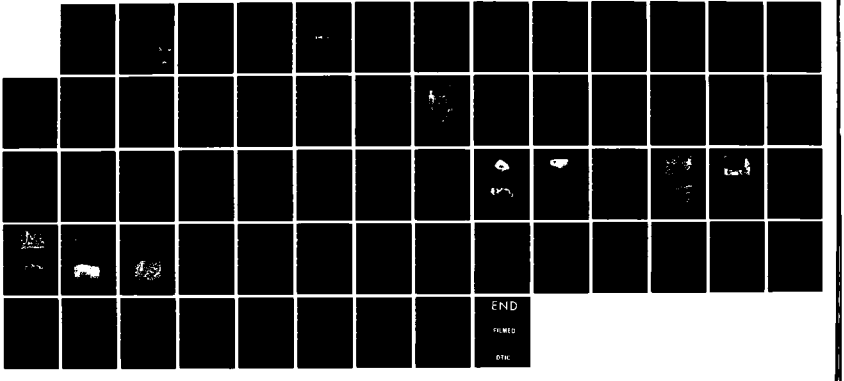

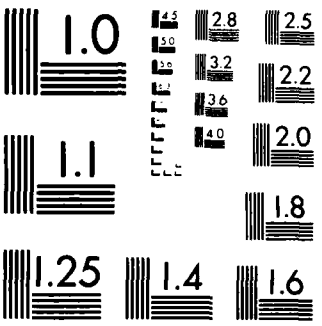

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BEHAVIOR DEGRADATION DUE TO 1100-RAD PULSED RADIATION EXPOSURE (5.8:1 NEUTRON/GAMMA RATIO)

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October 1984

Final Report for Period June - December 1982

Approved for public release; distribution is unlimited.

USAF SCHOOL OF AEROSPACE MEDICINE
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NOTICES

This final report was submitted by personnel of the Vulnerability Assessment Branch, Radiation Sciences Division, USAF School of Aerospace Medicine, Aerospace Medical Division, AFSC, Brooks Air Force Base, Texas, under job order 7757-05-50.

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely Government-related procurement, the United States Government incurs no responsibility nor any obligation whatsoever. The fact that the Government may have formulated or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication, or otherwise in any manner construed, as licensing the holder, or any other person or corporation; or as conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

The animals involved in this study were procured, maintained, and used in accordance with the Animal Welfare Act and the "Guide for the Care and Use of Laboratory Animals" prepared by the Institute of Laboratory Animal Resources - National Research Council.

The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

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A self-paced, 3-light, 3-lever discrete avoidance behavioral task was used for further study of behavioral performance effects of a high-neutron, low-gamma radiation pulse exposure (average 1100 rads midline tissue, 5.8:1 neutron/gamma ratio). Eight rhesus monkeys were exposed at the White Sands Missile Range Fast Burst Reactor and tested daily for up to 5 days after exposure. On the exposure day, all eight subjects had significantly degraded response accuracy, seven had increased reaction-time scores, seven experienced productive emesis. One day after exposure, most subjects performed near baseline levels except for occasional brief period(s). At 2 days, two subjects were unable to meaningfully perform the behavioral task and were euthanatized. The other six subjects were more variable than on the previous day. Three subjects experienced additional emetic episodes. At 5 days, only two of the remaining four animals performed at any reasonable degree. It is unlikely that any animal could have performed on the sixth day.

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BEHAVIOR DEGRADATION DUE TO 1100-RAD PULSED RADIATION EXPOSURE

(5.8:1 NEUTRON/GAMMA RATIO)

INTRODUCTION

Nuclear weapons produce blast, thermal x-ray, and electromagnetic pulse as well as alpha, beta, gamma, and neutron irradiation. An aircraft frame protects the crew from the blast of an intermediate dose range (100-3000 rads). Thermal curtains or shields with PLZT flashblindness/retinal-burn protective window elements can be used to isolate crewmembers from the thermal effects (6). In the lower atmosphere, where most manned systems operate, x-rays produced during detonation are absorbed by the atmospheric gases in relatively short distances and are of little concern. Baum et al. (3) reported that the electromagnetic pulse environment minimally affects crewmembers even after exposure to 10^8 pulses of electromagnetic energy with amplitudes of 447,000 volts per meter. Therefore, of the components in the nuclear environment, nuclear radiation is the most significant contributor to crew effects.

Acute radiation (gamma) exposures spanning a wide range of doses have been described by Gerstner (12), Zellmer (35), Pickering et al. (25), and Albanese and Pickering (1). With whole-body sublethal doses--i.e., 100-300 rads gamma (midbody tissue)--human subjects exhibit mild to moderate prodromal reactions of listlessness, discomfort, weakness, anorexia, and possibly nausea and vomiting. With doses in the range of 300-800 rads, reactions are characterized by a higher probability and more rapid onset of nausea and vomiting, increased fatigue and lethargy, and then diarrhea. Exposure levels beyond 800 rads speed the onset of the above effects and may include extended periods of vomiting and prostration. In the intermediate dose range, these effects gradually abate after 10-12 h but may reappear after 2-3 days. Depending on the time of their onset and duration, some of these symptoms may moderately or severely impair the ability of aircrews to perform specific tasks.

More data about man's ability to operate after exposure to high-neutron/low-gamma environments is needed. The only large body of data for neutrons and nontherapeutic human exposure is the followup on the Hiroshima and Nagasaki survivors, and the relative value of that data has diminished with recent evaluation and revisions. The end point has been death rates from various types of cancers. Leukemia mortality rates appeared to be higher in Hiroshima than in Nagasaki. Based on tentative 1965 dose estimates, the differences were attributed to a much higher neutron component at Hiroshima (8). In 1980, William Loewe and Edgar Mendelson (19) sharply revised those bomb dosimetry estimates. Their proposed leukemia mortality dose-response curves show no difference between the two cities. They believe the neutron element was so low in both cities that only very limited conclusions can be drawn about the relative biological effectiveness of neutron and gamma radiation. The debate, however, is by no means settled.

The capability of Air Force systems to withstand exposure to a nuclear environment without losing their mission-completion capability is termed "systems nuclear survivability." Because man is a crucial part of Air Force systems, the identification of "sure safe" and "mission failure" radiation doses, with effects of time considered, is essential. Within limits, the aircraft frame and additional safety devices can provide protection from many nuclear-weapon effects but not from nuclear radiation. An enhanced-weapon's dispersion distances are considered to be significantly larger than those of current weapons, yield for yield. If a weapon is released from a low altitude, the crewmembers who drop the device may receive partial exposure from it. Therefore, we must understand the operational significance of behavioral-performance degradation; i.e., 1) the onset and duration of early transient incapacitation and performance decrement, and 2) immediate permanent incapacitation, although this would not be expected to occur at doses considered in this report.

Flying requires highly complex tasks that must be performed for extended periods of time. Normal aircraft operation involves many stressors including task complexity, workload, fatigue, and physical and psychological stress. How much stress small amounts of radiation add and its effect on mission completion must be assessed. Even with a protracted exposure, a total dose of 300 rads (gamma) has been shown to impair performance and increase reaction times (4, 34). Less is known about the behavioral effect of neutron doses; the equivalent number of rads (neutrons) apparently does not produce equivalent exposure effects. Examples of studies that compare gamma and neutron exposure effects are those by George et al. (11) and Thorp and Young (29).

The study by George et al. investigated the relative effectiveness of fission neutrons for performance decrement in the miniature pig. The incident neutron/gamma (n/g) ratio was 10:1; the dose rate was 2000 rads/min; and midbrain doses ranged from 1500 to 36,000 rads. The task for the pigs was to traverse on cue a two-chambered shuttlebox. Their response to supralethal doses from the neutron field was distinctly different than to similar doses from the gamma field. Early performance decrement, early transient incapacitation, and immediate permanent incapacitation all occurred at much lower doses from the gamma exposure than from the neutron. With early performance decrement and death within 48 h as end points and with the gamma exposure as the reference point, the relative effectiveness of the neutron field was 0.23.

Thorp and Young (29) evaluated the relative effectiveness of neutrons for causing early transient incapacitation in 58 monkeys (Macaca mulatta). The neutron/gamma ratio was 10:1; the dose rate was 2000 rads/minute; and the midbrain doses ranged from 2200 to 4400 rads. The task for the monkeys was a visual-discrimination two-choice problem, between a square and a circle. The subject had to press a lighted symbol displaying the square. Significantly higher neutron doses than gamma doses were required to elicit early transient incapacitation. The ED_{50} for the gamma field was 2186 rads (midbrain tissue dose); for the neutron field, 3215 rads. The difference was significant. The relative effectiveness for the neutron field in the study was 0.68 when compared to similar gamma exposures.

For early transient incapacitation, the relative effectiveness of similar neutron exposures was much lower for miniature pigs (0.23) than for monkeys (0.68). Also in the studies by George at al. (11) and Thorp and Young (29), the midthorax dose was higher for the gamma field than for the neutron, but the

difference was less in the study using monkeys (29). This could be an important factor in reported differences for relative effectiveness. Dose-rate differences have been considered as a variable in relative biological effectiveness (RBE) type studies, but dose-rate effects are generally attributed to rates less than 1000 rads/min. The rates used by George et al. and Thorp and Young were beyond the general area of dose-rate concern. Other factors responsible for the RBE difference include the different tasks or animal species used. However, the conclusions of the above studies are still in the same direction--gamma exposures produce greater postirradiation performance decrements generally attributed to central nervous system disturbances than do similar neutron exposures.

The purpose of this study was 1) to examine the effect of neutrons in order to better define dose levels and effects that might impact specific Air Force sorties, specifically at 24 and 48 h after exposure (although our data collection continued for 120 h), and 2) to document the gross and microscopic pathology induced by high-neutron/low-gamma exposure. A review of the results from gamma-exposure studies led us to anticipate that the dose level selected for this study would produce moderate radiation effects as related to mission completion. The task and schedule arrangement 1) contained periods of moderately heavy workload (a correct response every 2 s), 2) had an uncomplicated arrangement between stimulus and required response, 3) allowed each subject to establish his own pace in operating the task, 4) permitted a significant shift in the pace (faster or slower) but with a response that could still be classified as correct, 5) had a moderately undesirable consequence (shock) for an incorrect response, and 6) had task length sufficient to produce mild fatigue (as a function of duration and workload).

METHODS AND PROCEDURES

Subjects

Eight male American-born rhesus (Macaca mulatta), ranging between 2.9 and 3.3 kg, were randomly selected from the USAF School of Aerospace Medicine (USAFSAM) colony and trained to operate the three-lever Multiple Avoidance Program (MAP) described later.

Clinical evaluation and chemistries were used to ensure that the monkeys were in good health prior to exposure. The animals were necropsied to ensure that clinical impressions and data obtained prior to exposure were not biased by disease undetected by conventional methods.

Training. Each subject was individually hand trained by standard shaping techniques until performance was sufficiently stable for training by laboratory programming equipment. Initially each subject was trained for about 1 h per day. The shock level was approximately 3.0 mA for 0.3 s duration. Once avoidance was consistent (95%) on the center lever, the other two levers were phased in. Training sessions were gradually increased up to 4 h (to match 4-h test sessions). Subjects were trained in 12-min work periods followed by 3-min rest periods. This cycle continued throughout training and testing conditions.

Diet Control. At the beginning of each work period, each animal received a monkey biscuit and a small piece of fruit. This facilitated catching and restraining; it also simulated a subject with a small amount (snack) of food in the stomach. When returned to the home cage, each subject was fed a normal food ration (8-10 biscuits and 1 whole orange). Feeding times were constant to facilitate observation for emesis during exposure.

Task

The MAP panel (Fig. 1) was located directly in front of the animal. When one of the red lights was lighted, the subject was allowed 2 s to press the lever directly below that light to extinguish it. Failure to press within 2 s or pressing one of the two incorrect levers resulted in a small shock (2.0-3.0 mA) to the feet of the subject for 0.3 s. At the end of the 2-s response interval or when the subject pressed a lever, the lighted lamp was extinguished immediately and one of the other two was lighted. Thus, a stimulus cue lamp never repeated, and the speed of presentation was established by the animal as long as a response occurred within 2 s. Some subjects established work rates (set their own pace) of almost twice that of some other subjects.

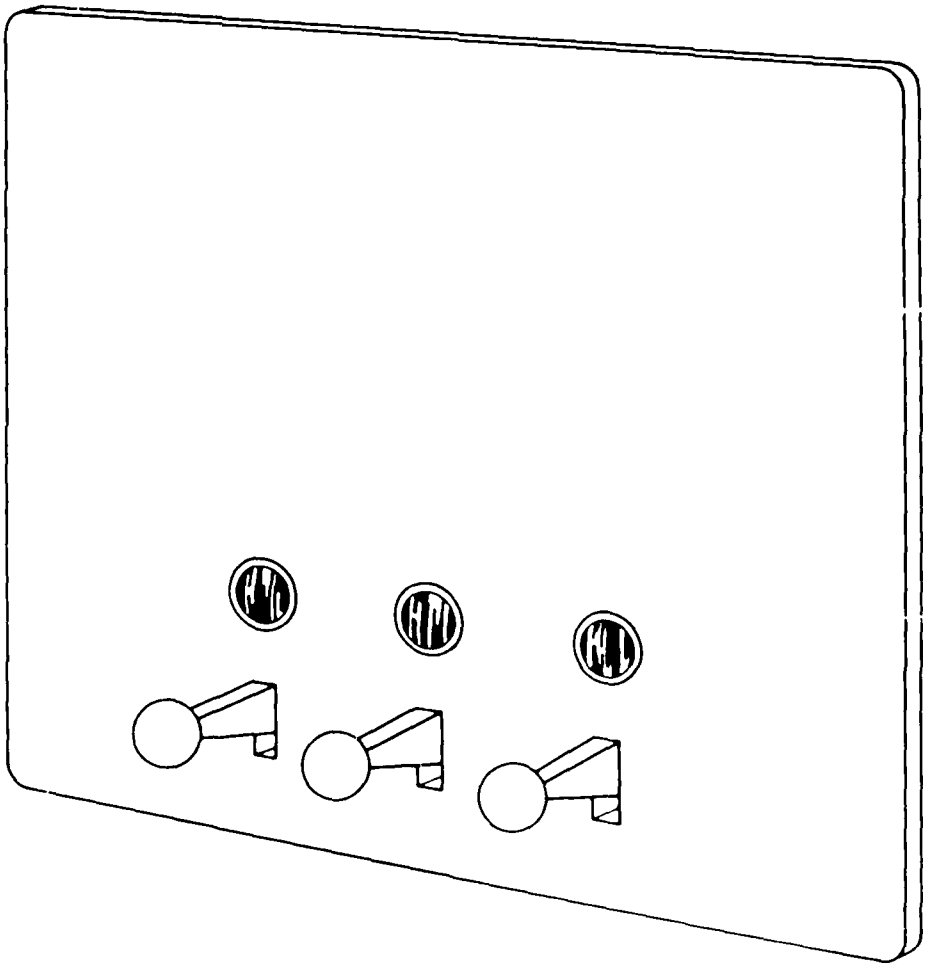


Figure 1. Animal response panel.

Equipment

Each subject was placed in an individual cubicle (2'x3'x4') to minimize external distractions. The booth was power ventilated, and a small amount of light entered near the top-opening door.

All programming was done with Digibit equipment manufactured by BRS/LVE. The order of stimulus presentation was randomized in six balanced blocks of 24 trials per block, determined individually for each subject by a punched-paper-tape reader. This allowed each animal to work at his own pace.

Complete data was summarized each minute and dumped to punched papertape for backup. Identical data was simultaneously transmitted to a DEC MINC (11/23 computer) for recording on RX02 floppy disks. Collecting the data in machine readable format saved time in subsequent analysis. The MINC also permitted display of the data in real time. This immediate feedback was useful in monitoring performance and helped in detecting equipment problems during the course in testing.

Photography

All photography and video recording were by White Sands Missile Range (WSMR) personnel. Before leaving the exposure cell at the end of each work session, the animals were still-photographed as a group. As soon as they were back in their individual holding cages, a 3-min video recording was made of each animal. For some typical animals, the edited video recordings have been paired with the subject's performance for each day. The purpose was to compare the general appearance of the animal (which may be poor) with his performance scores (which may be near baseline levels).

Exposure Procedures

The eight subjects were always tested in two groups of four. Each group (morning or afternoon) was fed 1 h before its work period started. See Table 1 for an account of daily activities.

The exposures occurred 30 min after the start of the work period, so 90 min had elapsed since the snack (e.g., 1 biscuit and 1 orange slice) had been consumed. The small amount of food in an animal's stomach at the time of exposure was significantly less than his normal ration of 8-10 biscuits and 1 whole orange.

Dosimetry

The exposure parameters required to deliver an 1100-rad pulsed midline dose (neutron + gamma) to a 3.0-kg primate exposed in a training booth to the Fast Burst Reactor (FBR) were determined via dosimetric measurements in Alderson neutron-tissue-equivalent primate phantoms approximating the size of the animal to be used in the experiment. The phantom exposures were conducted in training booths identical with the ones used by the animals. Free-field measurements were also conducted.

TABLE 1. SCHEDULE FOR TESTING AT WHITE SANDS MISSILE RANGE

Day 1 — Travel to WSMR
Set up equipment

Day 2 — Acclimation and Checkout (baselines 1 and 2)
0700 - Feed snack to Group I
0800 - Begin subject baseline testing of Group I
1130 - Feed snack to Group II
1200 - Remove Group I
Still-photograph Group I in cell
Videotape individual animals
Feed daily food ration to Group I
1230 - Begin subject baseline testing of Group II
1630 - Remove Group II
Still-photograph Group II in cell
Videotape individual animals
Feed daily food ration to Group II

Day 4 — Rest day for animals

Day 5 — Baseline 3
Repeat day-2 schedule

Day 6 — Baseline 4
Repeat day-2 schedule

Day 7 — Exposure day
0700 - Feed snack to Group I
0800 - Begin subject testing of Group I
0830 - Expose Group I
1130 - Feed snack to Group II
1200 - Remove Group I
Note emetic activity
Still-photograph Group I in cell
Videotape individual animals
Feed daily food ration to Group I
1230 - Begin subject testing of Group II
1300 - Expose Group II
1630 - Remove Group II
Note emetic activity
Still-photograph Group II in cell
Videotape individual animals
Feed daily food ration to Group II

Day 8 — (24 hours after exposure)
Repeat day-2 schedule

Day 9 — (48 hours after exposure)
Repeat day-2 schedule

Day 10 — (72 hours after exposure)
Repeat day-2 schedule

Day 11 — (96 hours after exposure)
Repeat day-2 schedule

Day 12 — (120 hours after exposure)
Repeat day-2 schedule
Euthanatize and necropsy remaining subjects

Day 13 — Travel
Return to Brooks AFB, Texas

On the basis of phantom dosimetric measurements, the required core-temperature size (ΔT_3) of 250°C and exposure distance of 54" were established. To corroborate the programmed exposures, dosimetered phantoms and monitor dosimeters were exposed with each group of animals.

From a free-field dose value at 54" of 7 rads per °C of reactor core-temperature change (ΔT_3) and a midline/free-field dose ratio of 0.7 obtained from dosimetry measurements in May and July 1981 (5), we established that a midline dose of approximately 1200 rads could be attained with a reactor core temperature of 250°C. For corroboration, a dosimetry primate phantom was exposed on 3 August 1982 (Op 9612). The phantom was exposed P-A in the primate booth at a midline-to-reactor-center distance of 54" (137 cm). Figure 2 illustrates the dosimeter exposure configuration used in the phantom exposures. The results of the phantom measurements for this operation are listed in Table 2. The average total midline dose was 1247 rads, with an average midline neutron/gamma dose ratio of 5.8:1. We considered this adequate for the experimental requirements, and the reactor operators were instructed to try to duplicate this pulse in the animal exposure.

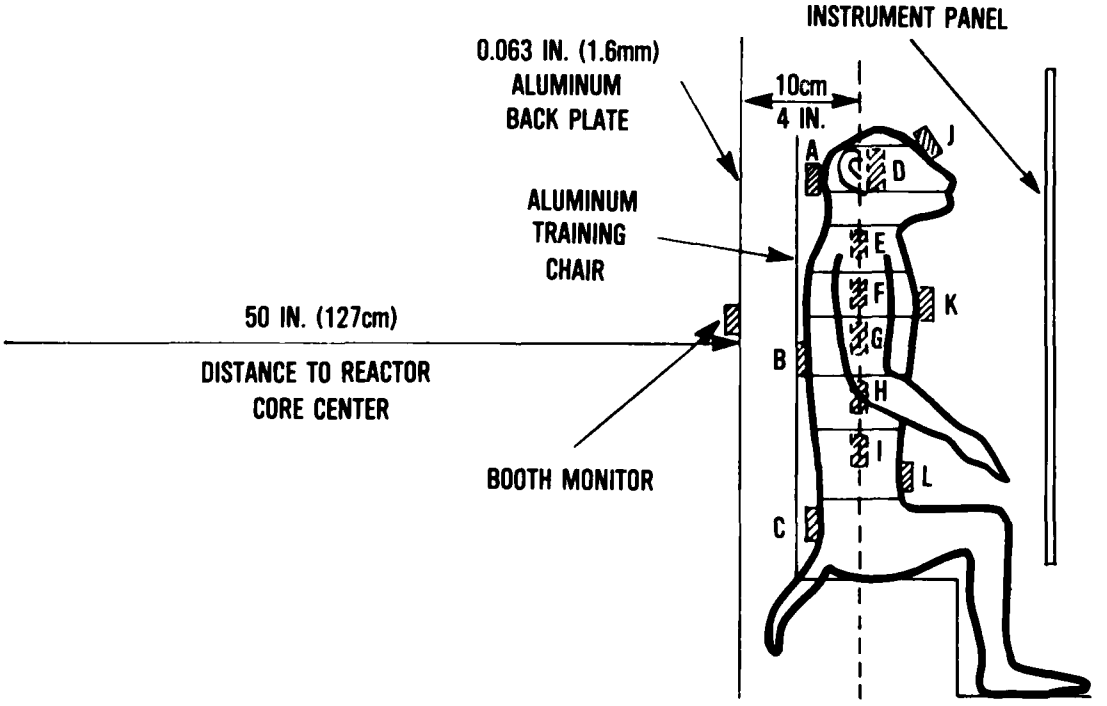


Figure 2. Exposure configuration for phantom dosimetric measurements at WSMR FBR, 3 August 1982.

TABLE 2. RADIATION DOSES MEASURED IN TEST PHANTOM EXPOSURE (WSMR FBR, 3 AUG 82, OP 9612, ΔT_3 = 276°C)

Dosimeter position	Gamma dose (rads)	Neutron dose (rads)	Total dose (rads)	N/G Dose ratio
Posterior				
A	209.2	1548.9	1758.1	7.4
B	229.6	1600.4	1830.0	7.0
C	191.5	1352.9	1544.4	7.1
		Average:	1710.8	7.2
Midline				
D	166.1	1184.4	1350.5	7.1
F	192.5	1144.1	1336.6	5.9
H	189.0	940.6	1129.6	5.0
I	188.3	984.3	1172.6	5.2
		Average:	1247.3	5.8
Anterior				
J	115.2	502.8	618.0	4.4
K	136.7	491.7	628.4	3.6
L	147.5	553.6	701.1	3.8
		Average:	649.2	3.9
Free-field at 54"	184.6	1431.0	1615.6	7.8
Booth monitor	233.8	1816.3	2050.1	7.8

$$\frac{\text{Average midline total dose}}{\Delta T_3} = 4.52 \text{ rad/}^{\circ}\text{C}$$

$$\frac{\text{Average midline total dose}}{\text{Monitor total dose}} = 0.61$$

$$\frac{\text{Average midline total dose}}{\text{Free-field total dose}} = 0.77$$

On 6 August 1982 two groups of primates, four animals each, were exposed on the FBR--one group in the morning (Op 9614) and one in the afternoon (Op 9615). A dosimeter phantom and a free-field monitor were exposed at 54" with each group. In addition, booth monitors were exposed with each animal. Figure 3 illustrates the overall exposure configuration. The pulse of 3 August 1982 was not replicated. The core temperature sizes actually obtained for the two groups were 221°C, and 231°C, respectively, indicating a delivered dose somewhat lower than anticipated. The phantom dosimetry data obtained for these two operations are listed in Tables 3 and 4. The average midline doses measured in the phantoms were 1039 and 1108 rads respectively.

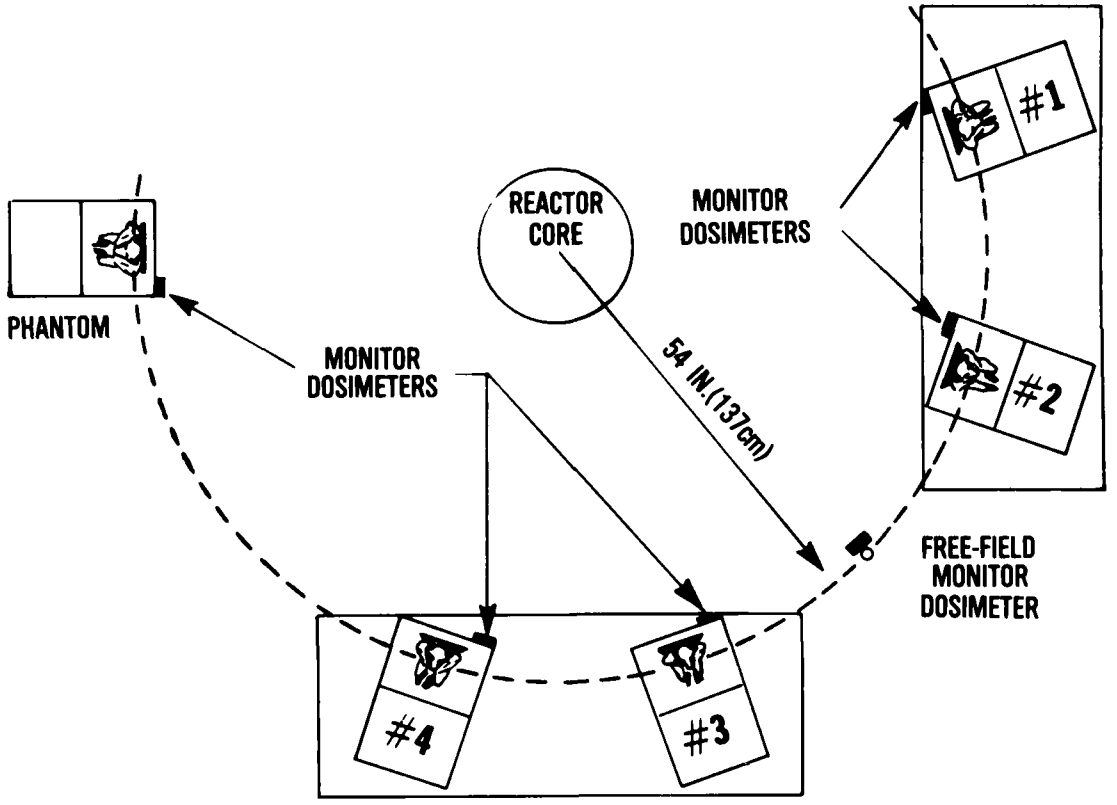


Figure 3. Animal exposure configuration for WSMR FBR experiments.

TABLE 3. RADIATION DOSES MEASURED IN PHANTOM EXPOSURE WITH ANIMAL GROUP 1 (WSMR FBR, 6 AUG 82, OP 9614, ΔT_3 = 221°C)

Dosimeter position	Gamma dose (rads)	Neutron dose (rads)	Total dose (rads)	N/G Dose ratio
Posterior				
A	165.4	1242.2	1407.6	7.5
B	181.4	1383.5	1564.9	7.6
C	166.2	1247.8	1414.0	7.5
		Average:	1462.2	7.5
Midline				
D	118.9	771.0	889.9	6.5
F	135.4	1026.8	1162.2	7.6
H	158.5	872.8	1031.3	5.5
I	157.4	915.7	1073.1	5.8
		Average:	1039.1	6.4
Anterior				
J	86.3	405.5	491.8	4.7
K	113.3	425.8	539.1	3.8
L	123.7	518.5	642.2	4.2
		Average:	557.7	4.2
Free-field at 54"	164.7	1212.8	1377.5	7.4
Booth monitor	194.4	1496.7	1691.1	7.7

$$\frac{\text{Average midline total dose}}{\Delta T_3} = 4.70 \text{ rad/}^{\circ}\text{C}$$

$$\frac{\text{Average midline total dose}}{\text{Monitor total dose}} = 0.61$$

$$\frac{\text{Average midline total dose}}{\text{Free-field total dose}} = 0.75$$

TABLE 4. RADIATION DOSES MEASURED IN PHANTOM EXPOSURE WITH ANIMAL GROUP 2 (WSMR FBR, 6 AUG 82, OP 9615, ΔT_3 = 231°C)

Dosimeter position	Gamma dose (rads)	Neutron dose (rads)	Total dose (rads)	N/G Dose ratio
Posterior				
A	179.9	*	*	
B	205.1	1458.1	1663.2	7.1
C	174.8	1200.7	1375.5	7.9
		Average:	1519.4	7.5
Midline				
D	133.4	828.4	961.8	6.2
F	162.0	998.0	1160.0	6.2
H	176.8	912.3	1089.1	5.2
I	166.8	1052.6	1219.4	6.3
		Average:	1107.6	6.0
Anterior				
J	116.0	*	*	
K	123.8	506.3	630.1	4.1
L	128.2	516.2	644.4	4.0
		Average:	637.3	4.1
Free-field at 54"	174.5	1321.5	1496.0	7.6
Booth monitor	209.1	1635.3	1844.4	7.8

$$\frac{\text{Average midline total dose}}{\Delta T_3} = 4.79 \text{ rad/}^{\circ}\text{C}$$

$$\frac{\text{Average midline total dose}}{\text{Monitor total dose}} = 0.60$$

$$\frac{\text{Average midline total dose}}{\text{Free-field total dose}} = 0.74$$

*Neutron dosimeter absent

Table 5 lists the results of the individual booth monitors. This data indicated average estimated midline doses of 1066 and 1118 rads to the respective groups. These were in good agreement with the phantom measurements. This data also indicated that all exposures were within ± 4% of the average.

Based on the phantom data, entrance and exit doses are approximately 1.38 and 0.55 times the midline dose. For the 1066-rad exposure (Op 9614), the entrance and exit doses were 1471 and 586 rads; for the 1118-rad exposure (Op 9615), 1543 and 615 rads. The average neutron/gamma dose ratios (± SD) based on the phantom data in Tables 2, 3, and 4 were as follows: midline, 6.0 ± 0.8; free field, 7.6 ± 0.2; entrance, 7.4 ± 0.45; and exit, 4.1 ± 0.4.

The gamma dose component was measured with type 700 LiF thermoluminescent (TL) powder dosimeters (Harshaw Chemical Co. Lot # 1-OL-1), which were read out on a Harshaw Model 2000 thermoluminescence analyzer at USAFSAM. Gamma doses were assigned by comparison of responses of the dosimeters exposed at the WSMR FBR with responses of dosimeters (from the same lot) exposed to known doses of cobalt-60 gamma rays.

TABLE 5. BOOTH MONITOR DOSIMETRY DATA (WSMR FBR, 6 AUG 82)

Operation 9614, ΔT_3 = 221°C

Booth	Animal ID	(No.)	Monitor total dose (rads)	Estimated midline dose (rads)*
1	156Z	1	1684	1027
2	190Z	2	1729	1055
3	318D	3	1810	1104
4	204Z	4	1771	1080
				Average: 1066 (± 33)

Operation 9615, ΔT_3 = 231°C

1	356D	5	1788	1091
2	348D	6	1801	1099
3	344D	7	1881	1147
4	346D	8	1863	1136
				Average: 1118 (± 27)

* Monitor dose x 0.61.

The fast neutron dose component was measured with dl-alpha-alanine, a free radical dosimeter system. The radiation-induced free radical response of the alanine was measured on a Varian Associates Model E-6 Electron Paramagnetic Resonance Spectrometer at USAFSAM; the peak amplitude of the free radical spectrum was used as the response. The dl-alpha-alanine measures both the fast neutron and gamma dose components. To determine the fast neutron dose (D_N), the response due to the gamma dose component (D_G) as determined with the TL dosimeters had to be subtracted. The D_N was determined from the following empirical relationship:

$$D_N = N\ (D_A - D_G)$$

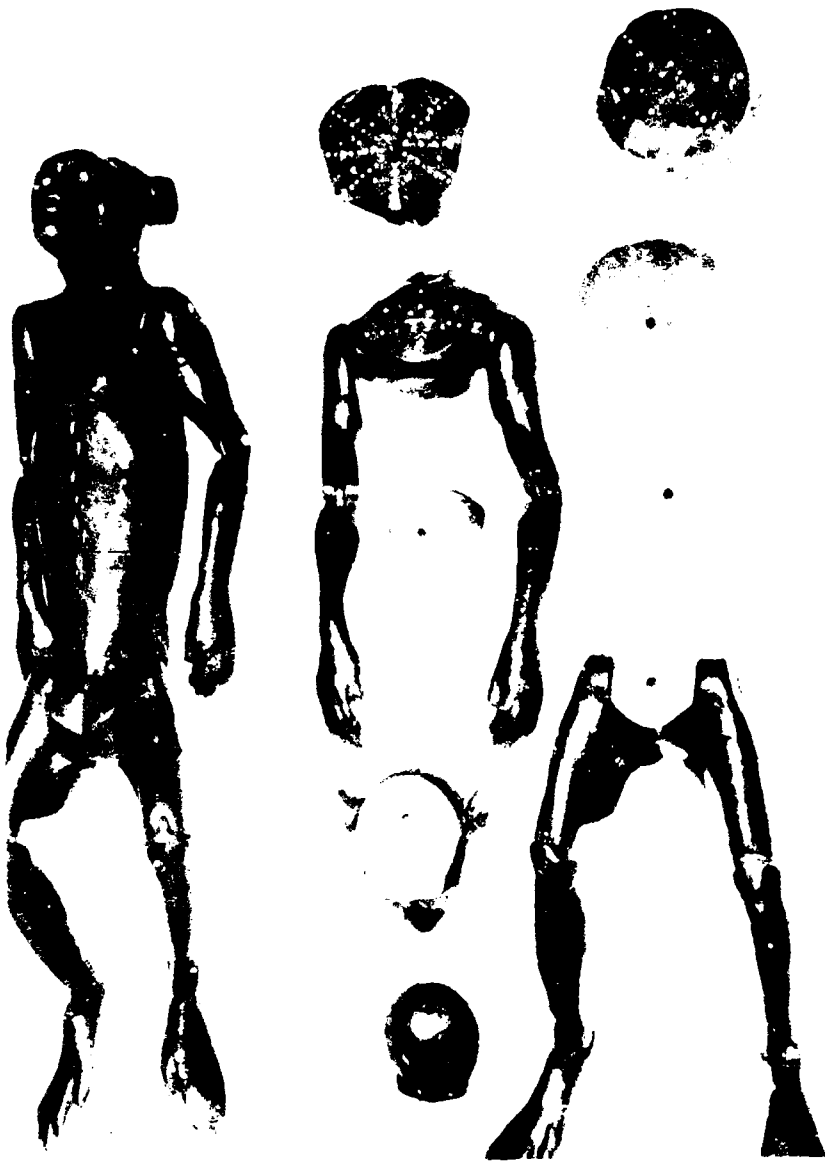
Where N = fast neutron dose conversion factor

D_A = Co-60 equivalent dose in rads

D_G = gamma dose in rads.

Previously N was determined to be 2.44 ($\pm$ 0.11 SD) by direct comparison with activation foil measurements exposed concurrently to the WSMR FBR spectrum (5). D_A was determined by comparison of total dose (neutron + gamma) response with a Co-60 gamma calibration set exposed on an Eldorado 78 Co-60 teletherapy unit at USAFSAM. The gamma output of this facility had been measured with ionization chambers having calibration factors directly traceable to the National Bureau of Standards. D_G was determined with type 700 LiF dosimeters.

The primate phantoms were constructed (Alderson Research Laboratories, Inc., 390 Ludlow St., Stamford, CT 06904-1271) of Alderson Plastinaut material with an elemental composition approximating soft tissue, especially with regard to hydrogen and nitrogen, thereby making this material "tissue equivalent" to fast neutrons. The phantoms (illustrated in Fig. 4) closely approximated in physical size the animals used in this experiment.



BEHAVIOR

Variables studied each day were accuracy (the number of errors) and correct-response times. Subjects were scheduled to perform on 10 occasions: four baseline runs; an exposure run; and postexposure followups at 24, 48, 72, 96, and 120 h. The first two baselines were used to test equipment and allow subjects to adjust to their new surroundings. The other two baselines were used as a standard against which each subject's performance could be judged on exposure and postexposure days.

Figures 5 and 6 show the accuracy for each subject on each test day. The plot points represent 12-min summaries (given in the Appendix). Subjects generally performed with near 100% accuracy on baselines 3 and 4, preceding exposure. This is indicated in Figure 5 by the overlapping of points forming a bold plot symbol.

On exposure day, the earliest accuracy decreases were noted within 12 min after exposure--in subjects 2, 3, 5, and 7, with respective accuracy scores of 83%, 76%, 97%, and 80%. (Subject 5's performance had never gone below 98% during baselines 3 and 4.) Within 42, 57, 72, and 117 min, subjects 1, 4, 6, and 8 experienced their first performance decreases--with respective scores of 93%, 95%, 75%, and 97%. The earliest decreases for four subjects (1, 2, 4, and 7) coincided with their lowest accuracy scores. Subjects 3, 5, 6, and 8 had their lowest scores--22%, 82%, 2%, and 69% respectively--at 42, 207, 162, and 192 min after exposure.

On postexposure day 1, subjects 1 and 6 had perfect scores; and subjects 3, 4, 5, 7, and 8 had near-perfect scores. Subject 2's diminished accuracy began about 150 min into the run and lasted about 50 min, with scores ranging from 87% to 97%.

On the second postexposure day, subject 6 continued to give perfect performance; subjects 1, 3, and 7 continued with near-perfect performance; and subject 2 returned to near-perfect performance. Subject 5's performance ranged between 95% and 99%; subject 4's, from 0 to 13%; and subject 8 could not work and was removed from the experiment.

By the third postexposure day, subjects 1, 2, 6, and 7 gave near-perfect performance, while subjects 3 and 5 had varied performance. During his last 2 h of performance, subject 5's accuracy ranged from 95% to 99% in contrast to his near-perfect baselines. Subject 3's accuracy did not diminish until his last 90 minutes of performance, when it ranged from 93% to 97%.

On the fourth day, subjects 1, 3, 5, and 6 gave near-perfect performances. Subjects 2 and 7 did not. During the first half-hour, subject 2's accuracy fell from 99% to 30%. His second half-hour yielded no performance, so he was withdrawn from the study. Subject 7's decline was more gradual; after having scores in excess of 94% for 3 h 15 min, this subject faded to 35% during the next hour. He was also withdrawn from the study.

By the fifth postexposure day, four subjects remained, two from both morning and afternoon. Three continued to work but no longer with near-perfect performance. Subject 1's scores varied between 84% and 99%; subject 5's, between 99% and 99%; and subject 6's, from 60% to 97%. Subject 3's scores were 97-99% during his first hour; during the next three 15-min periods, his scores fell to 77%, 4%, and 1% respectively. He was then withdrawn from the study.

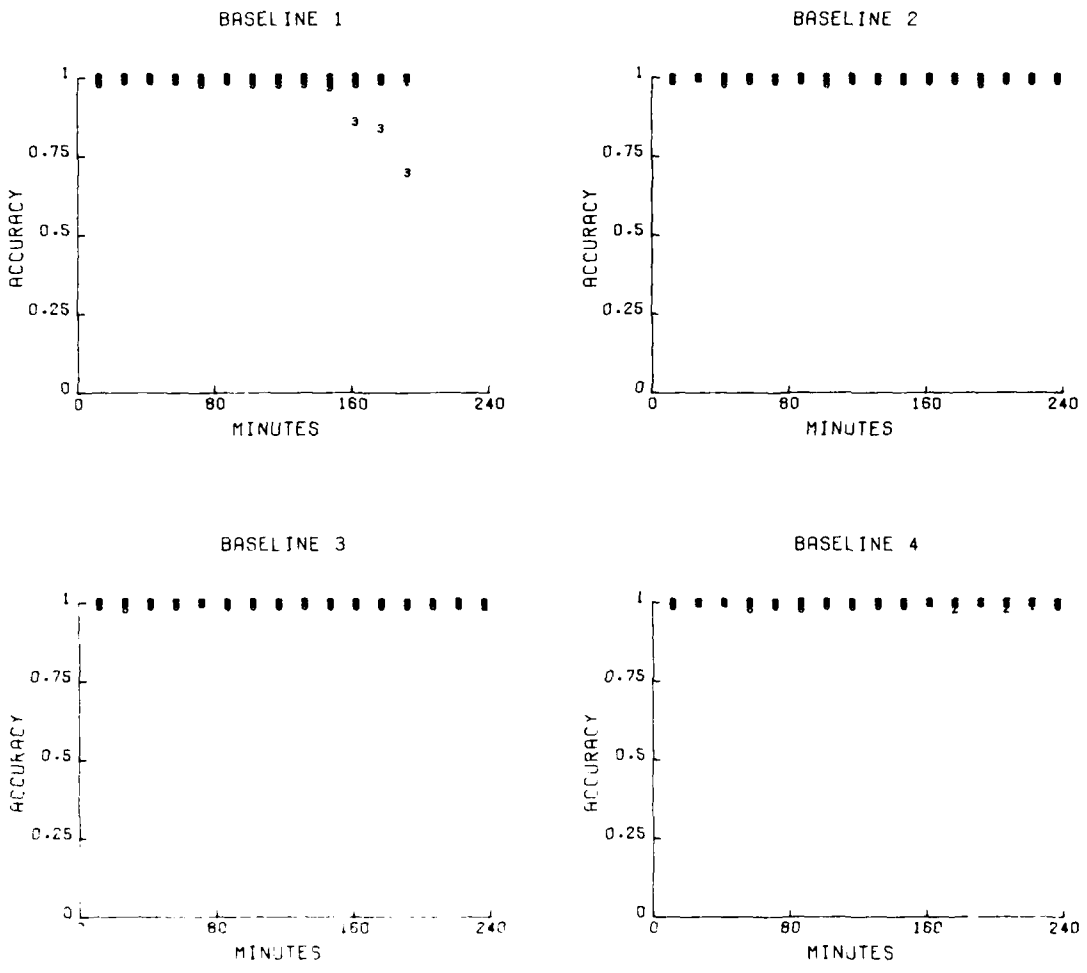


Figure 5. Baseline accuracy. Subjects are numbered 1 through 8, and the scores are computed over 12-min intervals (followed by 3-min rest periods). Dark spots indicate where subjects' performances overlap.

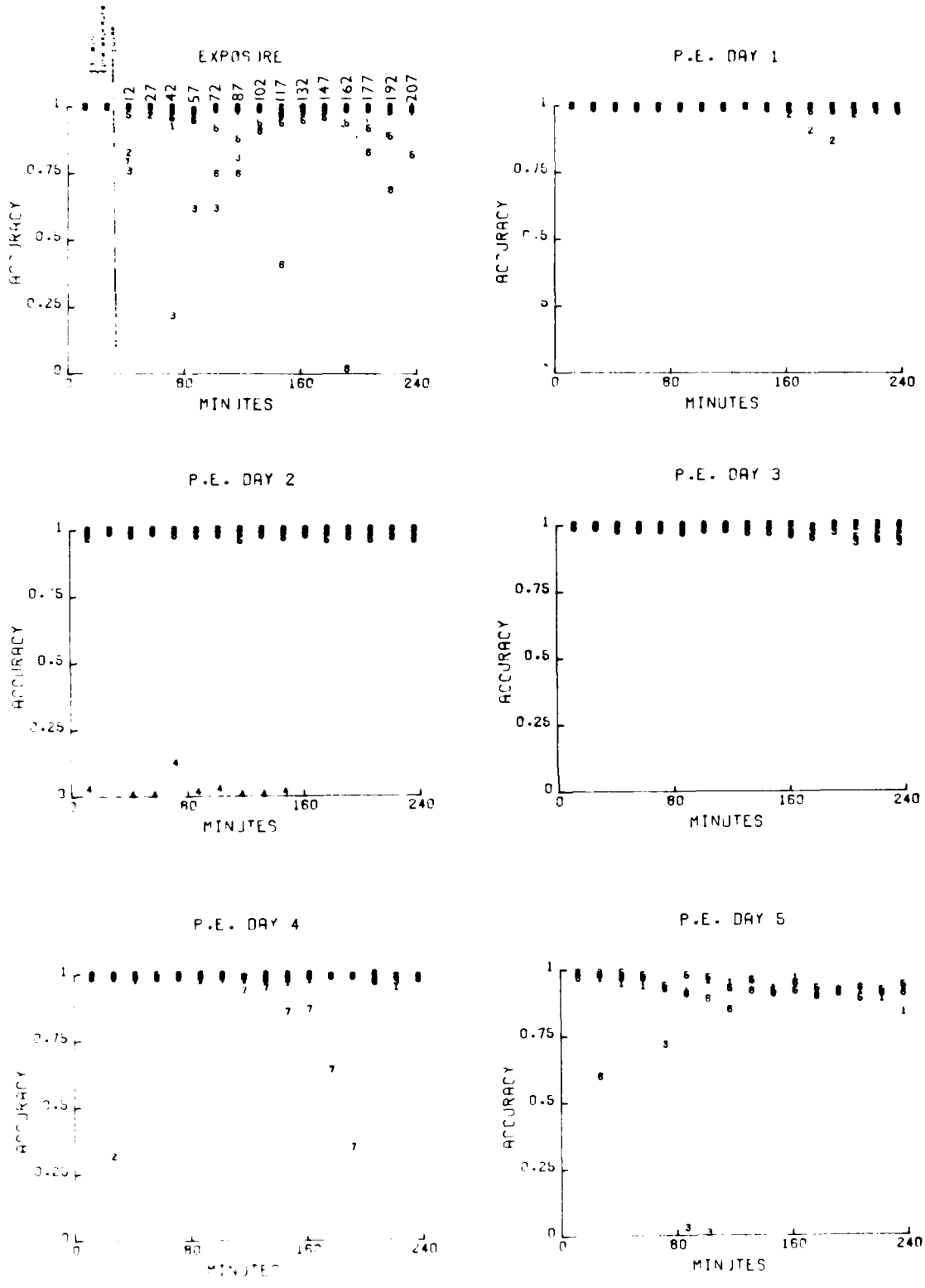


Figure 6. Accuracy on exposure and postexposure (P.E.) days. Subjects are numbered 1 through 8, and scores are computed over 12-min intervals (followed by 3-min rest periods). Dark spots indicate where subjects' performances overlap. The neutron pulse occurred at 30 min on exposure day.

Understanding what a MAP accuracy represents will help place these performance scores in perspective. Table 6 summarizes the total number of errors made by each subject on each test day. Errors included both failing to respond and pressing the wrong response lever when a stimulus was presented. Table 6 also lists the total number of presentations ("trials") for each test day. Subject 156's performance on the fifth postexposure day occurred within 5916 presentations for that day: an accuracy of 93.5%. By most standards, a score of 93.5 is good. In this case, however, the subjects were highly trained and their performance rarely varied by more than 1-2% prior to the stressor. The 384 errors represents a factor of 32-38 increase in the number of errors this subject made under baseline conditions--a substantial change in performance. For this reason we will compare test days by means of the number of errors made on each test day.

TABLE 6. (PERFORMANCE ERRORS)/(NUMBER OF TRIALS) FOR 4-H TEST PERIOD ON EACH TEST DAY

Subject--ID		Baselines		Exposure day	Postexposure days				
		3	4		1	2	3	4	5
1	156	17/8008	12/8570	51/7157	11/8283	50/7089	57/6527	93/6769	384/5916
2	190	19/9392	41/12774	130/9313	135/9764	53/8338	59/7593	236[a]/583	WD
3	318	24/[illegible]	4/8486	783/7164	28/8888	62/7548	150/6925	67/7184	698[b]/2603
4	[illegible]	17/[illegible]	14/10553	63/9856	58/10322	2089[c]/2710	WD	WD	WD
5	[illegible]	3/[illegible]	13/[illegible]	354/6678	78/7252	157/6395	181/6250	72/6572	314/5909
[illegible]	[illegible]	4/[illegible]	5/[illegible]	1445/7977	10/[illegible]	10/[illegible]	45/9713	39/9346	630/6738
[illegible]	[illegible]	1/[illegible]	4/[illegible]	174/7475	14/[illegible]	42/[illegible]	32/[illegible]	921[d]/5141	WD
[illegible]	[illegible]	2/[illegible]	1/[illegible]	[illegible]/[illegible]	5/[illegible]	WD	WD	WD	WD

WD = withdrawn.

[a] Subject withdrawn during 3rd half-hour.

[b] Subject withdrawn during 5th half-hour.

[c] Subject withdrawn during 4th half-hour.

[d] Subject withdrawn during 8th half-hour.

Figures 7 and 8 show the reaction times for a correct response. The Appendix contains a complete data summary. There is generally more variability in the metric because each subject responds at his own pace within the 2-s response window. Under baseline conditions (Fig. 7) overall reaction times ranged from .5 to 1.0 s; each subject's reaction times were generally linear and flat. Subject 5 was the slowest responder; subjects 2, 4, 6, and 8, the fastest.

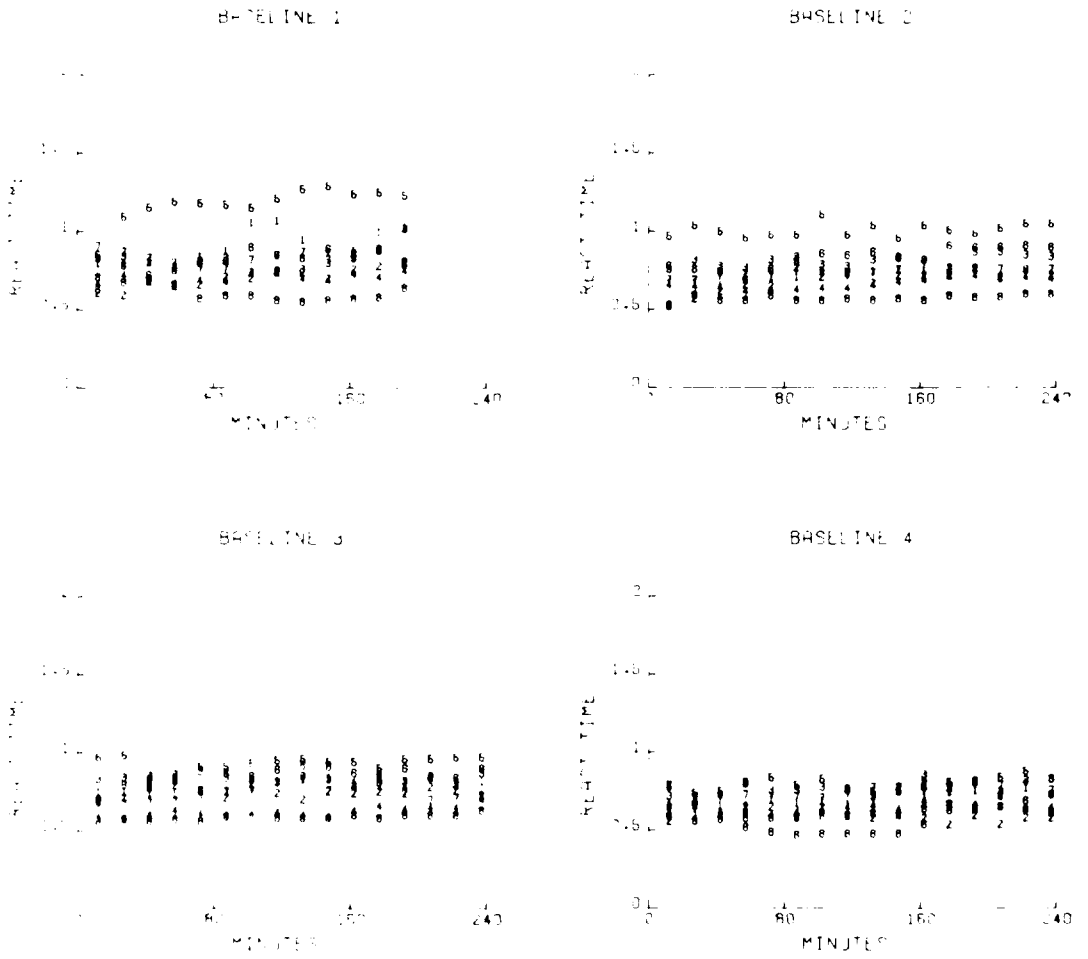


Figure 7. Baseline reaction time for a correct response. Subjects are numbered 1 through 8, and scores are computed over 12-min intervals.

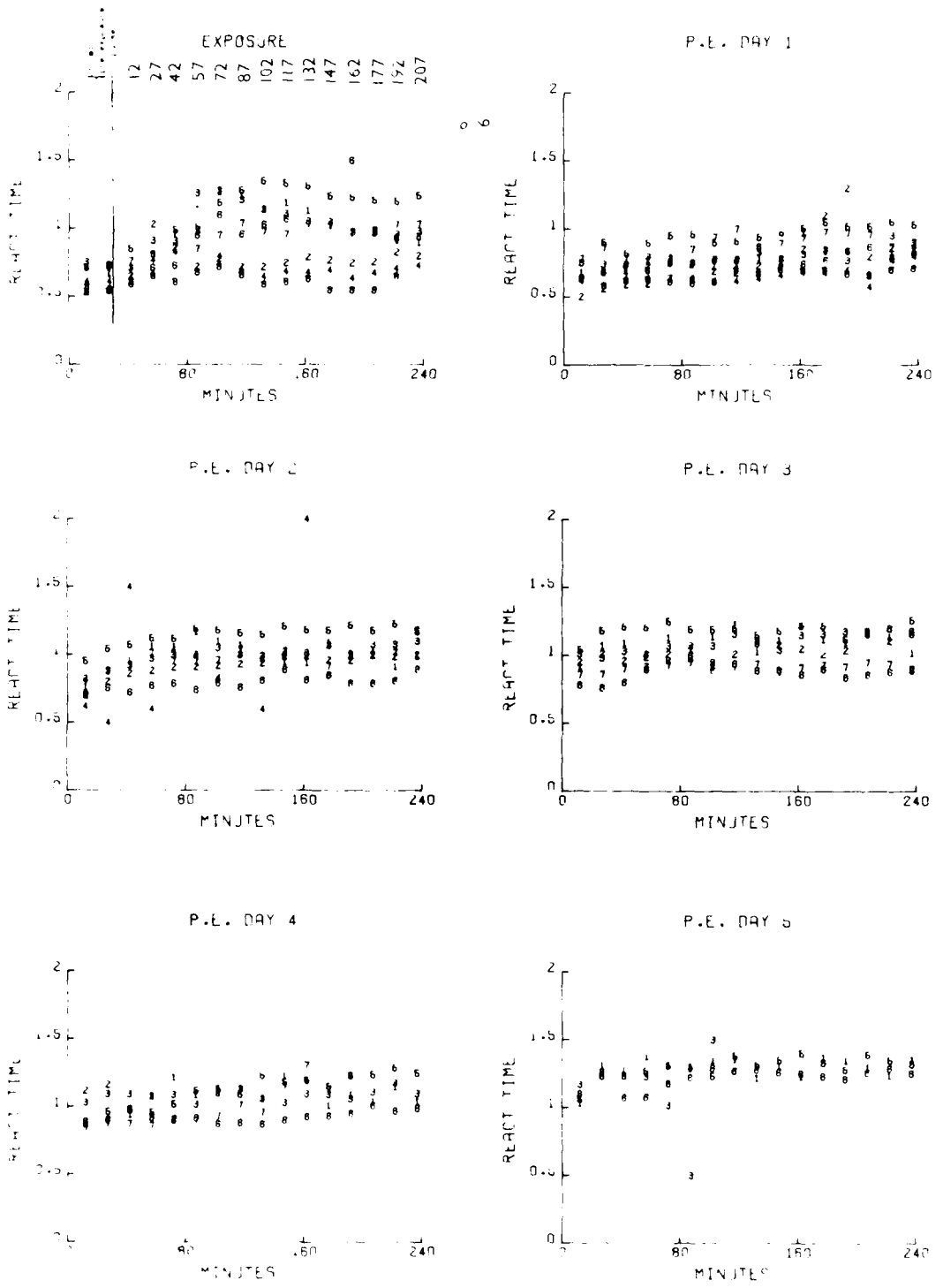


Figure 8. Reaction times on exposure and postexposure days. Subjects are numbered 1 through 8, and scores are computed over 12-min intervals. The neutron pulse occurred at 30 min on exposure day.

During the 30-min preexposure period on exposure day, the subjects' response patterns were generally similar to the preceding baselines. In particular, the scores were within the same range (.5-1.0 s); they were linear; they were flat; and the fastest subjects (2, 4, 6, 8) maintained their ranking. After the neutron pulse, reaction times slowly rose in all subjects except number 8, whose reaction times remained flat. Variability increased in all subjects, and new maximum reaction times were reached. Subjects 2, 3, and 4 were the first to exceed their maximum baseline reaction times, by 27 min after exposure; later that day their respective maximums became 1.03, 1.28, and .98 s, yielding net increases of .21, .40, and .28 s over their maximum baseline scores. Subjects 1, 5, and 7 were next, exceeding their baseline maximums at 42 min after exposure; their new highs were 1.27, 1.35, and 1.04 s, for net maximum increases of .42, .37, and .21 s. Subjects 6 and 8 were among the fastest baseline responders and among the last to exceed their baseline maximum reaction times; 57 min after exposure, their new maximums were 1.5 and .72 s, for net increases of .58 and .05 s. These results are summarized in Table 7, with the percent of time that exposure-day maximums exceeded baseline maximums. Statistically, by a sign test, the increase in maximum reaction times in 8 of 8 subjects is a significant event.

At 24 hours after exposure, responses were returning to baseline patterns. Subjects 2, 4, and 8 were still considered to be among the fastest responders, and 5 the slowest. For all subjects response times were considerably less variable than on exposure day; they were generally linear, flat, and ranged from .5 to 1.0 s.

By the second postexposure day, quick-responding subject 8 was unable to perform and was removed from the experiment. Subject 4, another quick responder, exhibited variable response times ranging from .5 to 2.0 s and was withdrawn from the study. Subjects 2 and 6 had the quickest responses, but with greater variability than on previous days. Subject 5 maintained his position of having the consistently slowest responses, with times generally in excess of 1.0 s. The responses of the other subjects, more variable than before, continued to range between .5 and 1.0 s.

On the third postexposure day, subjects 1, 2, 3, and 5 were consistently taking 1 or more s to respond; subject 5 was still the slowest. Subjects 6 and 7, whose responses were the fastest, ranged between .75 and 1.0 s.

During the fourth postexposure day, subject 2 had to be withdrawn since he could not complete the sessions. Subjects 1, 3, and 5 continued to take more than 1 s to respond, and subjects 6 and 7 responded as they had on the previous day.

By postexposure day 5, four subjects remained for testing. Subject 3 could not complete the 4-h performance period and was withdrawn. The remaining subjects (1, 5, and 6) each took more than 1.0 s to respond on the average during a 12-min trial. Their range (at baseline, .5-1.0 s) now stood between 1.0 and 1.5 s, i.e., an approximately 50-100% increase in correct response times.

TABLE 7. BASELINE VS EXPOSURE-DAY MAXIMUM REACTION TIMES

Subject No. -- ID		Baseline (s) b3, b4	Exposure day (s)	Net increase (s) over baseline	Time (min)* baseline is 1st exceeded	% Time over baseline
1	156	.85, .77	1.27	.42	42	75
2	190	.82, .66	1.03	.21	27	19
3	318	.88, .86	1.28	.40	27	81
4	204	.70, .69	.98	.28	27	38
5	356	.98, .88	1.35	.37	42	75
6	348	.92, .73	1.50	.58	57	64
7	344	.83, .81	1.04	.21	42	75
8	346	.53, .67	.72	.05	57	13

*After exposure.

Using Table 6 and ranking within subjects, a multiple comparison procedure based upon Friedman rank sums (16)* detected significant differences at the .05 level in contrasting the errors on all the test days against the last baseline day (b4). Exposure day and postexposure days 3, 4, and 5 had significantly more errors (over the 4-h test periods) than the last baseline. Table 8 shows how the errors were distributed over eight half-hour performance periods on exposure day. By the same test procedure and α-level, the total number of errors during the first through fifth and the seventh half-hour after exposure were significantly greater than the number of errors committed during the half-hour before exposure.

The average reaction time for the 4-h test period on each test day is summarized for each subject in Table 9. The table depicts increased reaction times in most subjects: on exposure day, six of eight subjects; at 24 h, five of eight; at postexposure day [illegible], six of seven; at days 3 and 4, six of six; and at day 5, four of four. Simultaneous comparison of all test days with each other, using multiple comparison procedures based upon Friedman rank sums (16),* leads to the conclusion that the average reaction times on postexposure days 4 and 5 were longer than on baseline b3 or b4 (α = .05). A more liberal procedure that compares all test days against the last baseline (b4) also found longer reaction times on postexposure day [illegible] (α = [illegible]).

*Subjects withdrawn from the study were assigned the highest ranks possible in order to complete the table for this analysis.

TABLE 8. EXPOSURE-DAY ERRORS DISTRIBUTED ACROSS EIGHT HALF-HOUR TEST PERIODS

Subject No. -- ID	Half-Hour Performance Periods: Preexposure	Postexposure 1	2	3	4	5	6	7	Total errors
1 156	1	1	36	6	4	2	1	0	51
2 190	0	98	18	3	0	3	2	6	130
3 318	0	101	393	207	45	14	10	13	783
4 204	0	11	31	8	3	1	8	1	63
5 356	0	14	36	72	41	34	53	104	354
6 348	1	0	12	199	253	600	372	8	1445
7 344	1	97	11	11	16	14	10	14	174
8 346	2	3	6	6	23	9	8	451	508
Total errors	5	325*	543*	512*	385*	677*	464	597*	3508

*Significant difference from preexposure period: $\alpha = .05$, by equation 20, p. 155, Hollander and Wolfe (16).

TABLE 9. COMPARISON OF AVERAGE REACTION TIMES

(a) Times (s) for 4-h Test Periods

Subject No. -- ID	Baselines b3	b4	Exposure day	Postexposure days 1	2	3	4	5
1 156	.72	.70	.98	.78	1.00	1.29	1.07	1.29
2 190	.75	.69	.75	.76	.92	1.04	1.14	WD
3 318	.84	.77	1.00	.79	1.00	1.10	1.09	1.13
4 204	.68	.64	.71	.67	.97	WD	WD	WD
5 356	.93	.80	1.10	.95	1.47	1.19	1.12	1.30
6 348	.68	.69	.90	.77	.79	.88	.93	1.22
7 344	.73	.76	.92	.88	.98	.92	1.00	WD
8 346	.63	.61	.61	.66	WD	WD	WD	WD

(b) Percent Change Over Baseline ($b_3 + b_4$) Reaction Times

Subject No. -- ID	Average b3 + b4	Exposure day	Postexposure days 1	2	3	4	5
1 156	.743	32	5	34	73	44	73
2 190	.723	11	13	36	54	69	WD
3 318	.805	24	-2	24	37	35	40
4 204	.738	12	6	54	WD	WD	WD
5 356	.865	27	10	70	38	29	50
6 348	.730	25	7	10	22	29	69
7 344	.745	23	19	32	23	34	WD
8 346	.620	03	11	WD	WD	WD	WD

WD = Withdrawn (animal unable to perform).

Each subject's reaction times were examined individually for radiation effects. The benefit of this approach is that it eliminates the "averaging out" of effects between subjects due to subject variability when reaction times might change. It also prevents averaging out effects within a given subject due to temporary excursions from his baseline behavior. We first fit baseline behavior with a least-squares line and then constructed the $p = 0.95$, $\alpha = 0.05$ tolerance limits of Lieberman and Miller (18) to identify a band of normal behavior about this line. Brown et al. (4) first applied this approach to reaction-time experiments. The method requires time-independent data. The Durbin-Watson test (24) indicated four instances that were correlated. Figure 9 shows the valid results. The least-squares line was fit to the baseline (3 and 4) data points. The upper and lower limits correspond to the $p = 0.95$, $\alpha = 0.05$ criterion. Scores above the upper limit represent reaction times significantly longer by this criterion; similarly, reaction times below the lower limit would be judged significantly shorter.

By this criterion subjects had increased reaction times as follows: on exposure day--subjects 1, 2, 3, and 5; on postexposure day 1--subject 2; postexposure days 2-4--subjects 1, 2, 3, and 5; and postexposure day 5--subjects 1, 3, and 5. Subjects 4, 6, 7, and 8 (eliminated from this analysis because of the significance of the Durbin-Watson test) exceeded their maximum baseline scores on test days as follows: subject 4 (withdrawn on postexposure day 3), on all test days; subject 6, on exposure day and postexposure days 3-5; subject 7 (withdrawn on postexposure day 5), on all test days; and subject 8 (withdrawn on postexposure day 2), on postexposure day 1.

We conclude that of the eight subjects, seven had increased reaction times on exposure day, and four on postexposure day 1. Allowing for withdrawals due to inability to perform, we found that six of seven subjects had increased reaction times on postexposure day 2, six of six on postexposure days 3 and 4, and four of four on postexposure day 5. All increases in reaction time on exposure day occurred after the pulse.

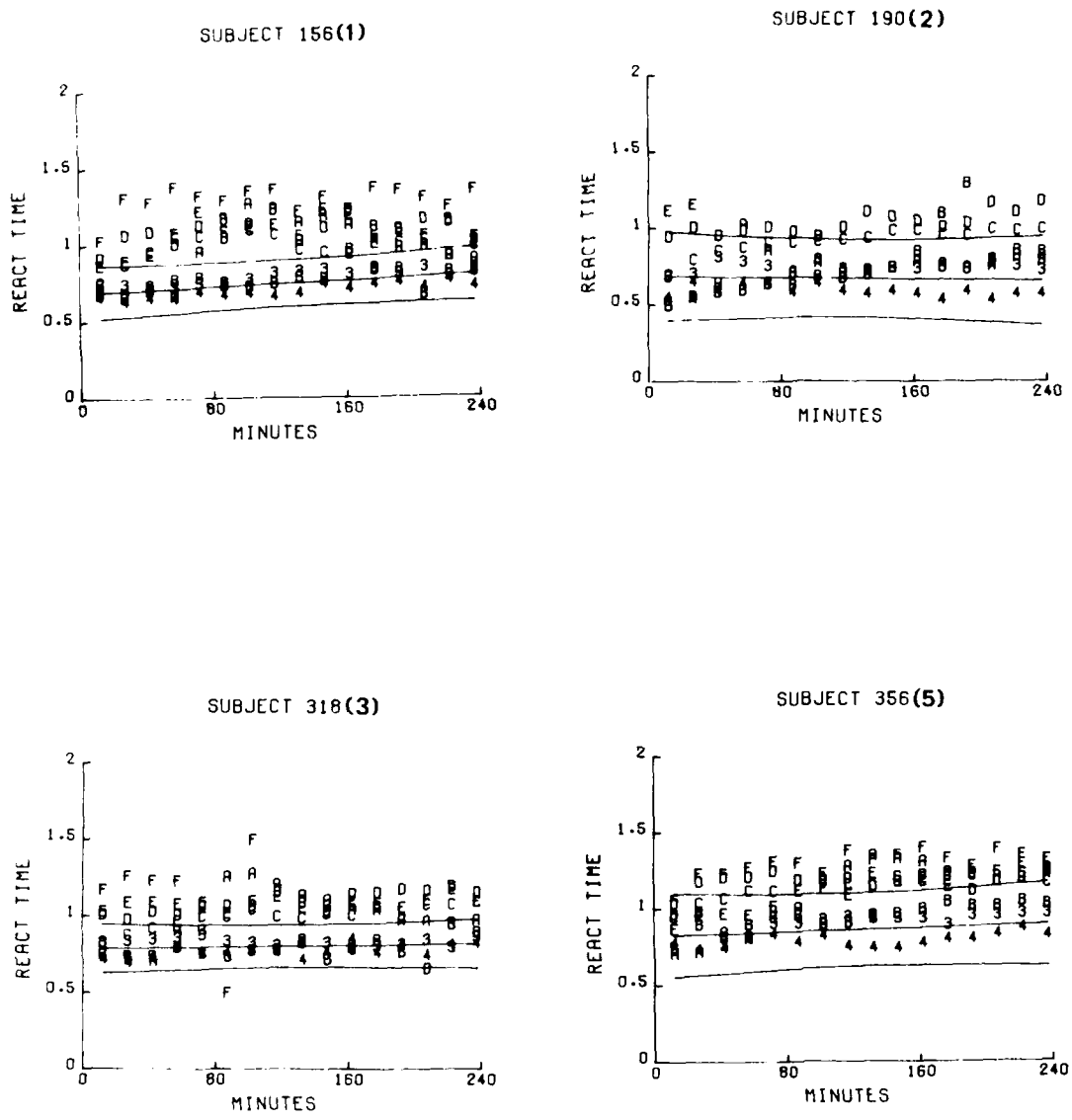


Figure 9. Least-squares lines fitted to baseline reaction-time data.
3 and 4 = baseline scores (reaction times) on days preceding exposure day.
A = exposure day (neutron pulse occurred at 30 min).
B, C, D, E, F = postexposure days 1, 2, 3, 4, 5 respectively.

A least-squares line was fit to the baseline scores computed over 12-min intervals, and surrounded by $p = .95$, $\alpha = .05$ simultaneous tolerance limits. By this criterion, scores above the upper limits are judged to be longer than baseline reaction times.

PATHOLOGY

Materials and Methods

The monkeys were euthanatized with 10 ml of T-61[R] intravenously via the right saphenous vein. Complete postmortem examinations were done immediately after euthanasia. All tissues were fixed in 10% buffered formalin, processed routinely, and stained with hematoxylin and eosin.

Clinical Evaluation

Prior to radiation exposure, the eight monkeys were alert, active, and clinically normal. When first seen, approximately 4 h after exposure, the major clinical signs were vomition, anxiety, and cachexia (Table 10). These signs were essentially the same in all subjects, except for one that apparently did not vomit. Several subjects had loose stools with perianal pasting of feces. The monkeys' health declined steadily for the remaining test periods, with cachexia, anorexia, and dehydration becoming more pronounced each day. Vomition was essentially absent on postirradiation day 1; but reoccurred on day 2 in three of the monkeys; two of these also had melena and muscle tremors, one with intermittent convulsions. The monkeys with convulsions and one with severe debility were euthanatized on day 2. One monkey began taking minimal amounts of food and water on postirradiation day 3, while the others were essentially anorectic. On day 4, one monkey developed epistaxis and gingival hemorrhages and was euthanatized due to extreme debility. All remaining monkeys were euthanatized on postirradiation day 5; one had developed epistaxis, three had melena, and four had gingival bleeding.

TABLE 3. [illegible] IN MONKEYS After INHALATION

Time after Irradiation	Subjects (No./Lb)							
	(1) 326	(2) 340	(4) 334	(3) 338	(7) 344	(8) 346	(6) 348	(5) 356
0 h	[illegible] cachexia anxiety	vomiting [illegible] cachexia anxiety	vomiting cachexia anxiety	vomiting cachexia anxiety	vomiting cachexia anxiety	vomiting cachexia anxiety	vomiting loose stool cachexia anxiety	vomiting cachexia anxiety
Day 1	cachexia mild anorexia	cachexia mild anorexia	cachexia mild anorexia	cachexia mild anorexia	cachexia mild anorexia	cachexia mild anorexia	cachexia mild anorexia	cachexia anorexia
Day 2	cachexia anorexia dehydration	cachexia anorexia dehydration vomiting melena tremors	cachexia anorexia dehydration vomiting melena tremors convulsions euthanatized	cachexia anorexia mild dehydration vomiting	cachexia anorexia mild dehydration	cachexia anorexia dehydration euthanatized	cachexia anorexia mild dehydration	cachexia anorexia mild dehydration
Day 3	cachexia anorexia dehydration	cachexia dehydration appetite improved		cachexia anorexia dehydration	cachexia anorexia dehydration		cachexia anorexia dehydration	cachexia anorexia dehydration
Day 4	cachexia anorexia dehydration	cachexia anorexia dehydration epistaxis gingival hemorrhage euthanatized		cachexia anorexia dehydration	cachexia anorexia dehydration		cachexia anorexia dehydration	cachexia anorexia dehydration
Day 5	cachexia anorexia dehydration gingival hemorrhage euthanatized			cachexia anorexia dehydration melena gingival hemorrhage euthanatized	cachexia anorexia dehydration gingival hemorrhage euthanatized		cachexia anorexia dehydration melena epistaxis euthanatized	cachexia anorexia dehydration melena gingival hemorrhage euthanatized

Gross Pathology

With a few notable exceptions, the eight monkeys had essentially the same gross lesions (Table 11). These lesions were recognized over time, with individual variations. The most notable and earliest gross lesion occurred in the two monkeys that were euthanatized first. They both developed hydrothorax, and their chest cavities were approximately half filled with a clear, dark-yellow fluid. The third monkey euthanatized due to general debility had moderate fluid distention of the pericardial sac. All eight monkeys when euthanatized were in progressive stages of emaciation and dehydration. Externally, seven of the eight had indications of clotting defects exhibiting one or all of the following: melena, epistaxis, and/or gingival hemorrhage. Internally, the most common changes were loss of body fat and dark reddening of lymph nodes, renal medullas, and gastrointestinal mucosas and contents (Figs. 10 and 11). Two subjects had marked reddening of the pancreata and surrounding tissues (Fig. 12).

TABLE 11. GROSS PATHOLOGY

Postexposure day euthanatized	Monkey #	Lesions
Day 2	204 (4)	dehydration; hemorrhage: kidney, lymph nodes, pancreas; hydrothorax; melena
	346 (8)	dehydration; emaciation; hemorrhage: pancreas, kidney, lymph nodes; hydrothorax; congestion of gastric mucosa
Day 4	190 (2)	dehydration; melena; hemorrhage: gingiva, myocardium, kidney, stomach, cecum; hydropericardium
Day 5	156 (1)	dehydration; emaciation; hemorrhage: gingiva, lymph node, rectum; congestion: rectum
	318 (3)	dehydration; melena; hemorrhage: gingiva, lymph node, stomach, large intestine, pancreas
	344 (7)	dehydration; emaciation; hemorrhage: gingiva, small and large intestine
	348 (6)	dehydration; melena; hemorrhage: lymph node, kidney, small and large intestine
	356 (5)	dehydration; emaciation; hemorrhage: gingiva, kidney, small and large intestine; melena

Figure 10. Cortico-medullary area of the kidney is black due to necrosis and hemorrhage. This gross lesion was recognized in all eight subjects.

Figure 11. Colonic lumen and focal areas of the serosal surface are black due to congestion and hemorrhage.

Figure 12. Pancreas is swollen and blackened due to severe hemorrhage, necrosis, and congestion.

Histopathology

All eight monkeys had essentially the same microscopic lesions with variable degrees of expression. The primary microscopic changes were necrosis, congestion, edema, and hemorrhage. Lymphoid necrosis and hypocellularity of bone marrow were recognized in all subjects (Figs. 13 and 14). The lymphoid necrosis was present in lymphoid tissue throughout the body. Individual cellular necrosis was the main expression of cell damage in the salivary glands, adrenal glands, pancreata, testicles, gastrointestinal tracts, and kidneys. Necrosis was especially severe in the kidneys and in two subjects' pancreata.

Edema and congestion were most evident in the lungs, gastrointestinal submucosas, and lymph nodes. Extravasated erythrocytes were usually associated with the foci of congestion and edema. Marked hemosiderosis in the liver, lymph nodes, spleen, and adrenal glands was noted in one subject; minimal to moderate amounts were recognized in two others. The most severe and life-threatening microscopic changes were recognized in the kidneys, lymphoid tissues, intestines, adrenals, pancreata, and bone marrows.

The kidneys of all subjects had diffuse severe necrosis of renal tubular epithelium. The tubular lumens contained deeply eosinophilic proteinaceous material, sloughed epithelial cells, and mineralized necrotic debris. The glomeruli were not remarkable. The vessels of the kidneys were congested, and extravasation of erythrocytes into the interstitiums was minimal to severe (Figs. 15 and 16).

Pancreatic necrosis in six of the monkeys was minimal with scattered individual exocrine and endocrine epithelial cells undergoing degenerative change, recognized by karyorrhexis, cytoplasmic swelling, and hyperchromicity of nuclei. The two subjects with edema in their pancreata and diffuse severe necrosis and hemorrhage (Fig. 17) were the first to be euthanatized.

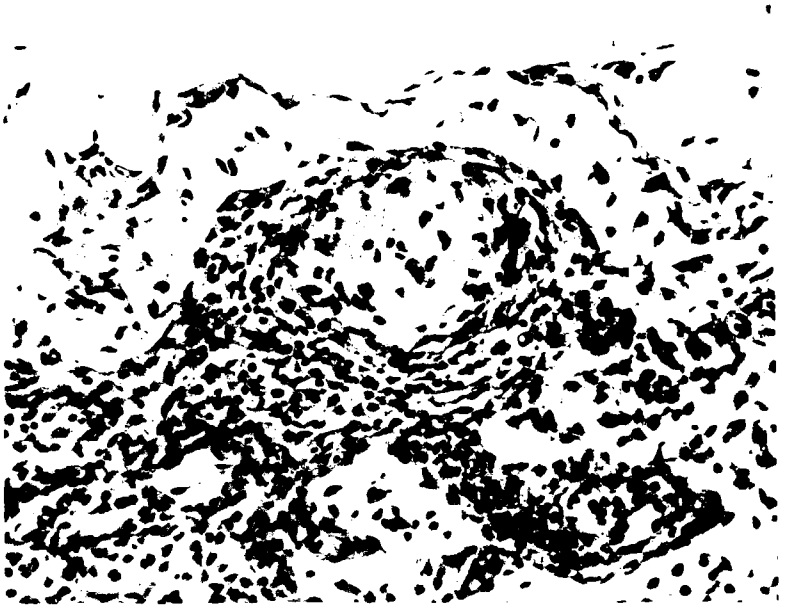


Figure 13. Lymph node follicle is hypocellular with loss of lymphocytes in the germinal centers, mantle, and medullary cords. The subcapsular sinus is dilated. H&E 270X.

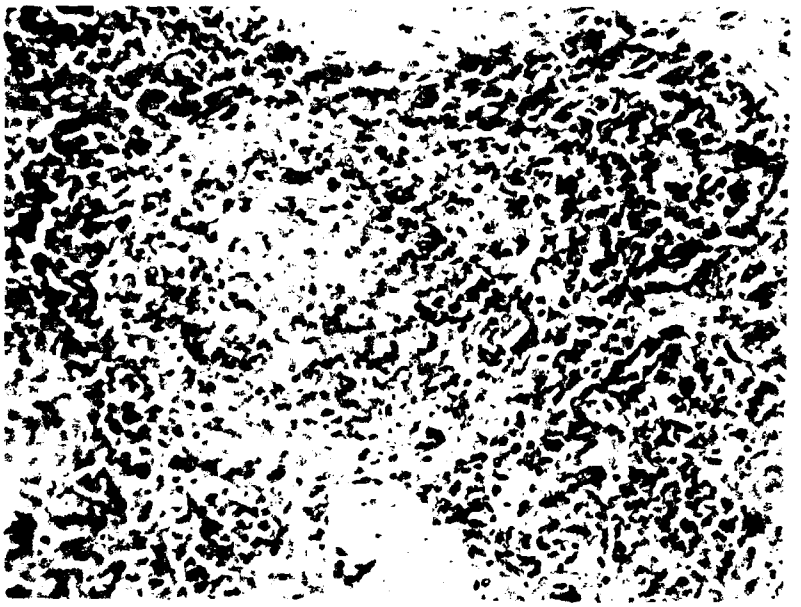


Figure 14. Splenic follicle is difficult to discern from surrounding parenchyma due to marked lymphoid hypocellularity. H&E 240X.

Figure 15. Renal cortical tubular epithelium -- diffuse necrosis with hemorrhage and proteinaceous material in tubular lumens and in the interstitium. H&E 93X.

Figure 16. Renal medullary collecting tubules contain sloughed renal cortical tubular epithelial cells occluding the lumens. H&E 155X.

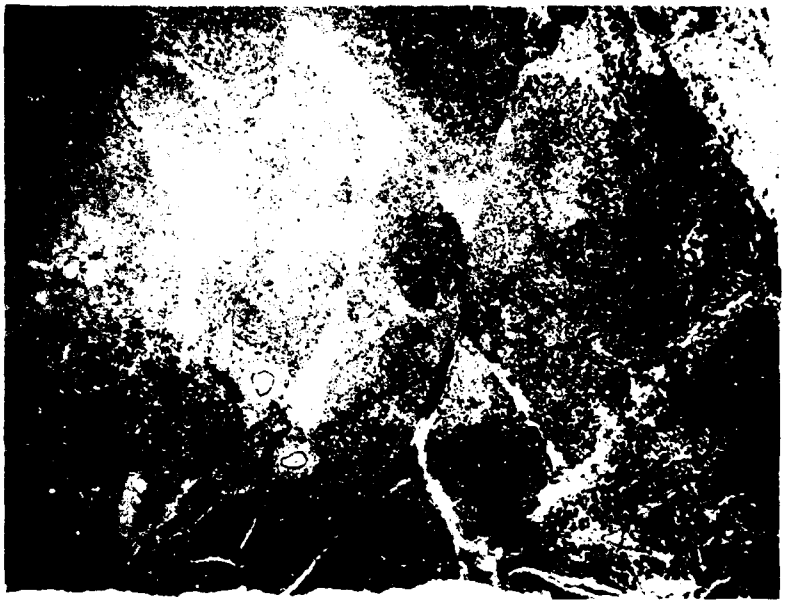


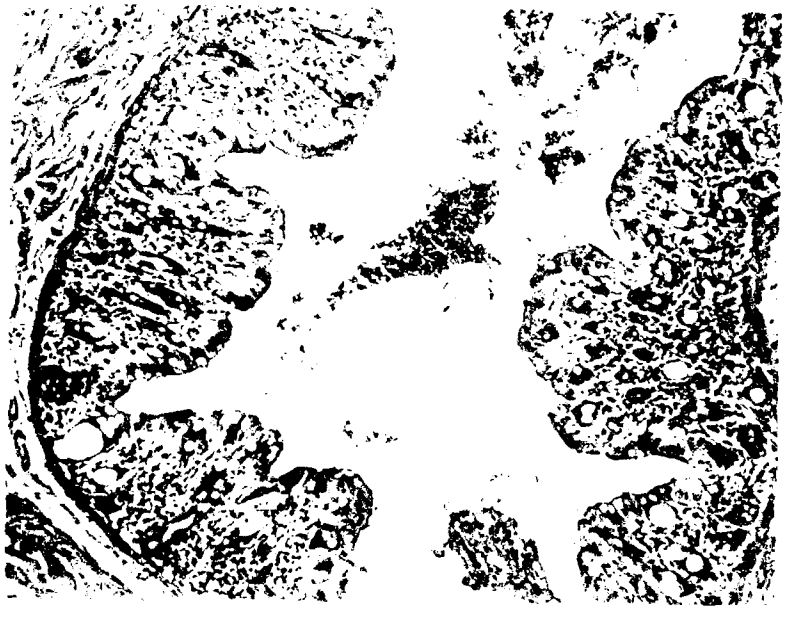
Figure 17. Diffuse severe pancreatic necrosis--hemorrhage, congestion, and moderate interlobular edematous change. H&E 230X.

Gastrointestinal changes were severe and diffuse throughout the length of the tract. The mucosas, submucosas, and occasional subserosal foci were edematous and often had collections of extravasated erythocytes within the edematous areas. The mucosal architecture was irregular with a marked decrease in crypt height, dilation of crypts, necrosis, and regeneration of epithelial cells. The mucosas were hypocellular with noticeable reduction of lymphoid cell populations (Figs. 18-21).

Lymphoid necrosis was recognized by loss of cells in the lymph nodes, spleens, thymuses, tonsils, laminae proprias, and mucosas of the body. The loss of lymphoid cells was not uniform among subjects, and in three it was minimal. There was a decrease in the small-lymphocyte population and a moderate loss of large lymphocytes. The germinal centers were essentially devoid of lymphocytes. The reticular cells did not have any remarkable changes. The loss of lymphocytes led to increased hypocellularity of the glands and edematous change. In tissues generally populated by scattered populations of lymphoid cells, there was a marked paucity of cells. Free erythrocytes and erythrophagocytosis were common in all subjects' lymph nodes.

The bone marrows were hypocellular in all subjects. A marked depression of the hematopoietic component accentuated the fat cells and vessels. Pyknotic nuclei were common. Immature and blast cells were rare (Fig. 22).

Adrenal necrosis was recognized as individual epithelial cell necrosis in five subjects. In four, the necrosis was multifocal to diffuse and severe, with edema and erythrocytic extravasation (Fig. 23). The necrosis was essentially confined to the cortex.



[illegible] of colonic mucosal height--crypt dilation, mucosal hypo-[illegible]arity, submucosal edema, and extravasation of erythrocytes [illegible] the colonic lumen. H&E 93X. (See Figure 19.)

[illegible] colonic lumen. (See Figure 18.) H&E 170X.

Figure 20. Crypts are lined with metaplastic epithelium. Note the sloughed necrotic cells in the dilated crypt spaces. H&E 340X.

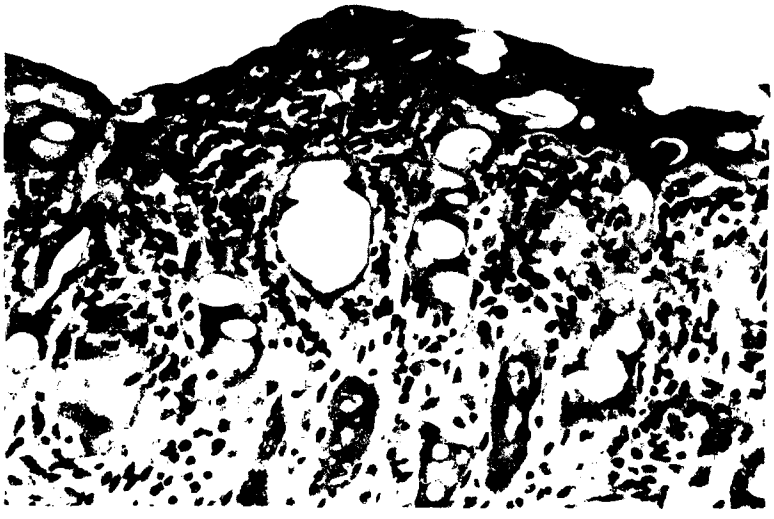


Figure 21. The erosive surface epithelium is markedly metaplastic. Mucosa is [illegible] and crypts are irregular and often dilated. H&E 270X.

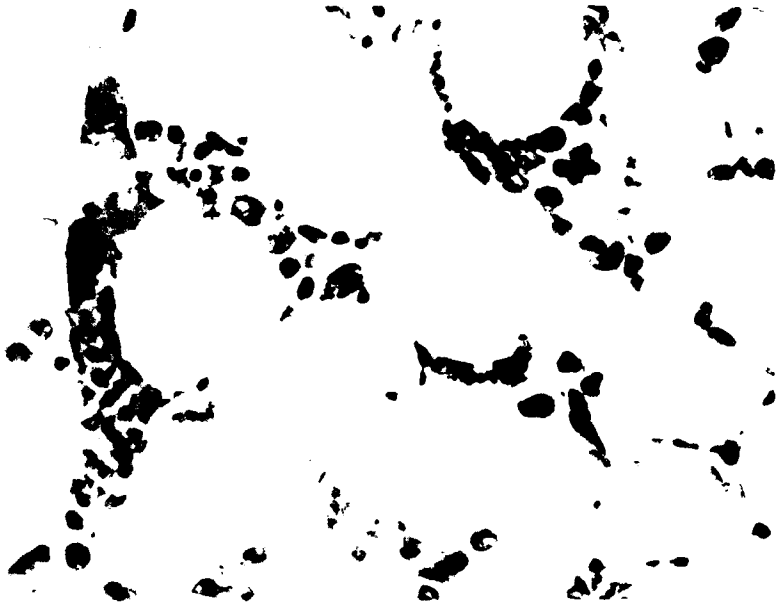


Figure 22. Bone marrow is markedly hypocellular with prominent fat cells. Note the paucity of blast cells. H&E 390X.

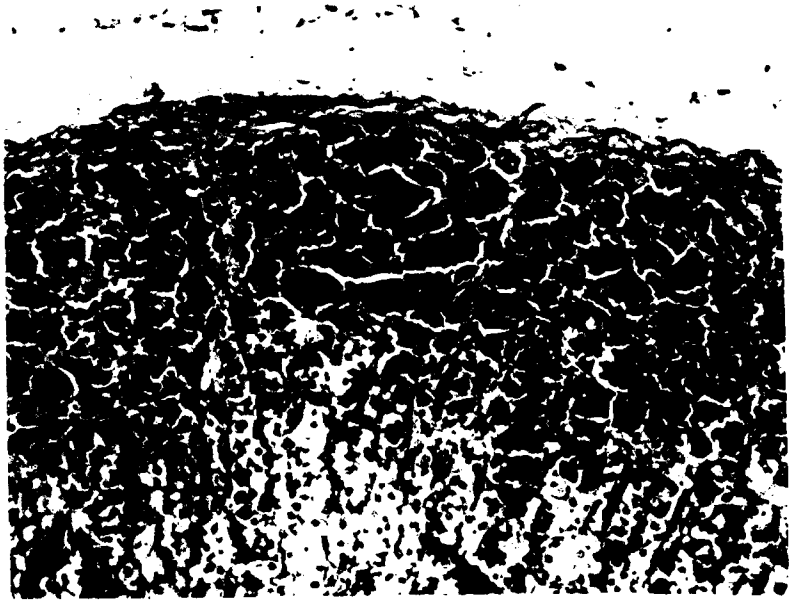


Figure 23. Severe diffuse adrenal cortical epithelial necrosis with hemorrhage and congestion. H&E 185X.

The lung changes included minimal to moderate congestion with accumulation of proteinaceous material in alveolar spaces. Minimal to moderate septal thickening, due to proteinaceous material, macrophages, and atelectasis, was occasionally recognized.

The salivary glands and testicles had similar changes, with individual cellular necrosis (Fig. 24). There was karyorrhexis, swelling of epithelial cell cytoplasms, and occasional pyknotic nuclei. No inflammatory cells were associated with necrosis in any of the organs.

Pyknotic nuclei were recognized in the cerebrums, cerebellums, and livers; these organs had no detectable necrosis, hemorrhage, or edema.

Focal myocardial necrosis was recognized in one subject. The focus was approximately one-half diameter of the ventricular wall, with discrete margins and no inflammatory cell infiltrates. The individual myocardial fibers were lightly eosinophilic and vacuolated and had no cross striations. Another subject had multifocal to diffuse myocardial hemorrhage but no detectable necrosis of myocardial tissue.

Marked hemosiderosis was recognized in one subject with accumulation in the liver, spleen, bone marrow, and adrenal and lymph nodes. Minimal to moderate hemosiderosis was recognized in two other subjects.

Additional lesions recognized in the monkeys were considered to be unrelated to the irradiation damage. The most significant were adrenal mineralization and accumulation of inhaled exogenous pigments in the lungs.

Figure 24. Individual cellular necrosis of the salivary gland acinar epithelium. Note the karyorrhexis and cytoplasmic swelling. This individual cellular necrosis was commonly recognized in salivary glands, testicles, adrenals, and pancreata. H&E 700X.

DISCUSSION

Pathology

Even though the pathogenesis of ionizing radiation is unknown, the pathology is well documented in many species (2, 9, 10, 13, 32). The lesions recognized in our eight subjects are of interest because of the essentially pure neutron radiation, the dose rate, and the single exposure. Additionally, a direct extrapolation to the radiation effects on humans exposed to comparable radiation can be made with few reservations.

The current understanding of tissue damage by radiation has led to the conclusion that the most important factor is that of cell killing (10, 26, 33). This is certainly the most notable cellular change recognized in these test subjects, with the necrosis varying from focal to diffuse and minimal to severe in major organs. Necrosis was recognized in the pancreata, gastrointestinal tracts, bone marrows, lymphoid tissues, kidneys, adrenals, salivary glands, and testicles. Necrosis in most of these organs has been well documented by other authors (2, 10, 13, 23, 26, 32, 33). Edema and hemorrhage were generally associated with necrotic tissues; and although vascular histopathology was not recognized, there is little doubt that it occurred. Not being able to see acute vascular damage with low levels of radiation is not unusual. Several authors indicate that endothelial damage is the most likely cause of the edema and hemorrhage ([illegible], 9, 17).

Our two subjects most seriously affected by radiation, and the first requiring euthanasia, both developed severe hydrothorax. They both had hemorrhage in many body sites and severe kidney damage. One had diffuse, severe pancreatic necrosis and hemorrhage. Another subject, and the third to be euthanatized, developed hydropericardium. Several authors comment on pulmonary edema, pneumonitis, and pleural effusions, but none specifically discuss hydrothorax and hydropericardium (10, 17, 28, 31, 32). These changes may be especially significant to subjects' performance and therapy in a neutron radiation environment.

Kidney necrosis was severe in all subjects, and predictably, the tubular epithelium was most damaged. Kidney pathology, while quite controversial for years, is well documented and readily accessible (7, 20, 23, 27, 3[illegible]).

Pancreatic necrosis is not well documented; severe pancreatic necrosis is [illegible] documented at all and may be a significant neutron radiation change ([illegible], [illegible]).

Adrenal necrosis is poorly documented (15); it is indicated to be a long-[illegible] with fibrosis, denoting earlier radiation damage (21). The [illegible] were acute, severe, and life threatening.

[illegible] intestinal changes, while marked and severe, were not [illegible] described by other authors in many species. [illegible]

Lymph[illegible] and bone marrow hypoplasia were recognized in all subjects [illegible], while variable in degree, were not an unusual histological finding in [illegible].

The hemosiderosis seen in one subject was probably due to rapid uptake and conversion of erythrocytic elements (32). This monkey had severe intestinal hemorrhage. No direct documentation of postirradiation hemosiderosis was found.

Pyknotic nuclei in the brain and liver are documented, even though the change is extremely difficult, if not impossible, to identify as a real morphologic change. The brain cells damaged by the radiation were most likely oligodendroglia. Hepatocytes were damaged in the liver. Radiation necrosis is well documented in the brain and liver (2, 9, 10, 30) but at much greater dosages than those used in this study.

The clinical picture that the monkeys presented was typical of ionizing radiation exposure in mammals, although the signs were apparently more marked than could possibly have been expected at the relatively low dosage (30). The severe lesions in the subjects would have no doubt been fatal and would have occurred even with supportive therapy. Since the monkeys were euthanatized, determining how long they could have lived is not possible; but it is unlikely they would have survived past 10 days, with the majority dying within 7 days.

Behavior

Neutron exposures at dose levels of 1050-1100 rads (5.8:1 n/g ratio) will most likely impair performance accuracy and cause a concomitant slowing in reaction time. The task in this study was rapidly paced, demanded periods of high output, and was mentally fatiguing; however, all baseline performance exceeded 99% accuracy (Table 6).

Parallels between the task loading of this study and operational aircrew tasks are easy to identify. Many operational situations require bursts of activity followed by reduced work rates or short rest periods. An increase of 3 to 6 times the operator's normal (acceptable) error rate would likely have a negative effect on total mission performance. Table 6 indicates that at least a factor-of-3 increase in errors occurred for all subjects on exposure day and for most subjects on postexposure days 2-5. Mission-essential subtasks have varying degrees of consequence for failure. Low-level and high-level cruise have greatly differing requirements for job performance. Landing an aircraft on land under ideal conditions is quite different than landing on an aircraft carrier in adverse weather conditions. Some jobs can tolerate limited errors, and some recovery is possible. Refueling, for example, is a task where errors (breakaways) are recoverable within limits. Too many breakaways, however, extend time required for refueling and can ultimately lead to mission failure.

The subjects in this study originally performed their task at a high level of accuracy. After the exposure, performance accuracy significantly decreased for all eight subjects, although not necessarily at the same time (see Table 8). In the first half-hour following the pulse, three of the eight subjects were apparently unaffected; but by 1 hr, only one subject appeared to be unaffected. Accuracy [illegible] on exposure day. Although dependent upon the [illegible] performed, a 15% reduction in performance accuracy [illegible] mission failure for some points in time.

After the 1100-rad neutron exposure, response rate was significantly delayed. One feature of the task was that an animal could change his response rate up to 2 s (most averaged under 1.0 s). If the response came after 2 s, the subject received a shock. Seven of the eight subjects had significantly increased reaction times on exposure day, four of eight at postexposure day 1, six of seven at day 2, six of six at days 3 and 4, and four of four at day 5. This shift to slower responding can be seen in Table 9b. On exposure day, reaction time increased by 11-32% over an average of the previous two baselines. Although the reaction time ranged from a 2% decrease to an 18% increase on postexposure day 1, it had a 40-73% increase for the four subjects performing on day 5.

A shift in the range for reaction times demonstrates that a subject is no longer responding in an expected manner. Many of the changes to slower responding were large. The subjects' ability had been degraded, although the "best" postexposure performance was seen on postexposure day 1.

Productive emesis was another variable of interest. The animals were monitored at the end of the 4-h postexposure work period. When removed from the work cubicle on exposure day, seven of the eight subjects in the 1100-rad group had vomitus on their fur, and two animals experienced an additional emetic episode later that day. At postexposure day 2, three subjects experienced additional emetic episodes. Most of the animals would uninterestingly consume small amounts of food 1 day after exposure but by the third day, most were ingesting almost no monkey biscuits, fresh oranges, Tang orange drink, or water. Depending on physical condition or termination of the study, the animals were euthanatized at the times indicated in Table 12.

To permit easy comparison of data, Table 12 summarizes the performance accuracy, reaction time, and emesis effects after radiation exposure for (a) present study--1100 rads and a 2-s response window, and (b) earlier study (5)--600 rads and a 3-s window. The most obvious comparison is that in the 1100-rad study, two animals were unable to perform meaningfully on the second postexposure day and so were euthanatized; in the 600-rad study, all eight animals were performing on the third day.

The 600-rad exposure generally resulted in moderate performance changes. In the 600-rad group, subjects were performing relatively well at postexposure day 3; the number of errors and subject loss are clearly greater for the 1100-rad group (contrast Table 13 with Table 6). It is quite likely that the subjects who received 600 rads could have worked reasonably well for up to 5 days because they were still consuming some food; however, only two of the four subjects in the 1100-rad group that started postexposure day 5 performed to any appropriate degree. Visual inspection of the animals, combined with virtually zero food or water intake (see Pathology section for possible reasons), made it doubtful that any animal could have performed to any meaningful degree on day 6.

TABLE 12. RADIATION EFFECTS

(a) 1100 rads, n/g 5.8:1
(behavioral response window = 2 s)

Subject No. -- ID	Exposure day	Postexposure days 1	2	3	4	5
1 156	A +		A +	A +	A +	A + S
2 190	A + E	A +	A + E	A +	A + * S	
3 318	A + E		A + E	A +	A +	A + * S
4 204	A + E	A +	A + E S			
5 356	A + E	A	A +	A +	A +	A + S
6 348	A + E			+	+	A + S
7 344	A + E	A +	A +	A +	A + *	S
8 346	A E	A +	S			

(b) 600 rads, n/g 5.5:1 (Ref. 5)
(behavioral response window = 3 s)

Subject No. -- ID	Exposure day	Postexposure days 1	2	3
1 176	A +			
2 178	A + E	A +	A +	A +
3 180	A E			
4 184	A + E		+	+
5 154	+ E	+	+	+
6 160	+			
7 L64	A + E	A	A	A
8 174	+ E	+	+	

A = Decreased accuracy defined by the presence of more errors on exposure and postexposure days than on either of the two control baselines.
+ = Increased reaction-time scores by simultaneous tolerance limits or exceeding both baseline maximums.
E = Emesis occurrence (productive).
* = Withdrawn during session due to inability to successfully perform.
S = Euthanatized.

TABLE 13. (PERFORMANCE ERRORS)/(NUMBER OF TRIALS) FOR 4-H TEST PERIODS FOR 600-RAD STUDY, N/G 5.5:1

Subject No. -- ID		Baselines	Exposure day	Postexposure days 1	2	3
1	176	16/7526	27/7537	12/8615	9/8111	9/8303
2	178	47/6656	142/6110	69/6675	230/5091	286/5167
3	180	27/6910	48/6907	11/8207	25/6407	17/6956
4	184	7/7126	26/6743	7/7018	7/6089	4/5832
5	154	39/8512	26/7589	7/7125	15/6926	14/6883
6	160	26/9307	10/9223	13/9992	5/8598	2/9028
7	164	30/7237	136/6358	37/7554	62/6918	34/7123
8	174	16/8473	12/7867	7/8291	16/6953	2/8204

An element of risk always exists when we take animal data, regardless of how good we believe it to be, and make generalizations to human operational tasks. These data can, however, suggest some guidelines. Below are some evaluations of the 1100-rad (current) and 600-rad (previous) exposure groups.

Previous Study (5) 600 rads, 5.5:1 n/g	Current Study 1100 rads, 5.8:1 n/g
1. Exposure will impact both performance accuracy and reaction time.	1. Exposure will have a marked impact upon both performance accuracy and reaction time.
2. For tasks without a low margin of error, performance can probably continue for several hours.	2. Performance will be able to continue within the first 4 h, although there will be periods (20-30 min) of poor performance.

3. For a task with a critically low tolerance for error, performance may be significantly compromised. Aircraft-carrier-based flying personnel would be apt to perform below safe standards; landing on a carrier (15-45 min after exposure) could very well be beyond an acceptable risk. Safety in land-based aircraft operations might be compromised, even in a normal take-off procedure, at 15-30 min after crew exposure.	3. For a task with a critically low tolerance for error, performance will be significantly compromised. Aircraft-carrier-based flying personnel would probably perform below safe standards within the first hour; landing on a carrier would be dangerously questionable for about 50% of the personnel. An additional 20% could be expected to perform poorly, and at times unacceptably, for up to 4 h, regardless of risk.
4. By 24 h after exposure, personnel would likely be available for reuse; but at 48 h, their speed of response for time-critical events would still be affected.	4. By 24 h after exposure, most personnel would be available for reuse although time-stressed tasks would suffer some degradation; by 48 h, response rate would be distinctly slowed, but accuracy would be only slightly worse than at 24 h. More significantly, there could be an approximate 20-25% total loss of usable personnel by this time.
5. Loitering should be possible for an extended period of time after exposure, with minimal or perhaps no crew redundance.	5. Loitering should be possible for an extended period of time, with personnel surviving up to 96 h. At 120 h, approximately only 20-25% of exposed personnel would be able to do their jobs.
6. Tasks required for penetration are very demanding and would be marginally affected 24 h after exposure. After 48 h, responses requiring speed would likely be jeopardized.	6. Skill levels required for penetration would be compromised for several hours after exposure, but marginally affected 24 h after exposure. At 48 h, tasks requiring rapid response would definitely be jeopardized and 20-25% of personnel would be unavailable (medical casualty) or useless.
7. Refueling would [illegible] successful if an increased [illegible] were possible. Additional breakaways would likely occur and lengthen the procedure. Activity at 24 h after exposure would experience the least difficulty; after 72 h, refueling would probably become more difficult.	7. Refueling would be seriously compromised within the first hour but probably successful within 3-30 h, particularly if an increased time element were possible. By 48 h after exposure, the surviving personnel (75-80%) would continue to be successful with additional time, although breakaways would unquestionably increase. By 72 h, performance would likely be plagued with breakaways.

8. The cruise phase of missions would suffer the least radiation-related problems. Because of lowered work rates, crews should accomplish tasks with limited difficulty. The opportunity to spread activity out in time somewhat should increase the expected success rate, but this may not be possible in a tactical situation where activity is at a continuous high level.	8. The cruise phase of missions would be minimally affected by radiation-related problems. Because of lowered work rates, surviving crewmembers should accomplish tasks with limited difficulty within 72 h after exposure. The opportunity to spread activity out in time would increase the expected success rate. After 120 h, however, it is unlikely that any operational crewmembers would be available.
9. As noted in Table 12, emetic activity, increased reaction time, and/or decreased accuracy may not coincide nor occur equally in all subjects.	9. As noted in Table 12, emesis appears up to 2 days after exposure. For this sample, increased reaction time and/or decreased accuracy generally occurred together (not true for the 600-rad group).

For the 600-rad data, behavior of the neutron-exposed animals was generally similar to that of animals exposed primarily to gamma radiation. In the current study, a more rapid death rate is easily associated with neutron exposures. Whereas gamma exposures generally result in an early performance decrement (EPD) for the dose levels discussed here, recovery time from the EPD appears to be longer for neutron exposures. To further identify the neutron/gamma relationship, it would be advisable to expose an additional group at 1100 rads, all gamma. The 1100-rad neutron exposures for this study definitely exceeded "threshold" dose. An all-gamma exposure would address the neutron RBE question as presented by the work of George et al. (11). Although their studies were good, they used different behavioral techniques and different species. The RBE question becomes increasingly important with the more recent shift in the types of nuclear weapons being considered (25).

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APPENDIX

THREE-MINUTE AVERAGE REACTION TIME AND ACCURACY SCORES[a]

(***** = missing data point)

[a]Overview in text Figures 5 and 6

EXPOSURE TO: 1100-RAD NEUTRON PULSE

SUBJECT 156 (1) VARIABLE ACCURACY

RUN

WORK SESSION	MIN	B1	B2	B3	B4	E	P.E.DAY1	P.E.DAY2	P.E.DAY3	P.E.DAY4	P.E.DAY5
1	12	0.990	1.000	1.000	1.000	1.000	1.000	0.990	1.000	1.000	0.990
2	27	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.970
EXPOSURE 3	12	1.000	1.000	1.000	1.000	1.000	1.000	0.990	0.990	1.000	0.950
4	27	1.000	1.000	1.000	1.000	1.000	1.000	0.990	1.000	0.990	0.940
5	42	1.000	1.000	1.000	1.000	0.930	1.000	1.000	0.990	0.990	0.930
6	57	1.000	1.000	1.000	1.000	0.980	1.000	0.990	1.000	0.980	0.920
7	72	1.000	1.000	1.000	1.000	0.990	1.000	0.990	1.000	0.990	0.960
8	87	1.000	1.000	1.000	1.000	0.990	1.000	1.000	0.990	0.980	0.950
9	102	1.000	1.000	1.000	1.000	0.990	1.000	1.000	1.000	0.990	0.960
10	117	1.000	1.000	0.990	1.000	1.000	1.000	1.000	0.990	0.970	0.930
11	132	1.000	1.000	1.000	1.000	1.000	1.000	0.990	0.990	0.980	0.970
12	147	1.000	1.000	1.000	1.000	1.000	1.000	0.990	0.970	0.990	0.910
13	162	0.990	0.990	1.000	1.000	1.000	1.000	0.990	0.990	0.990	0.920
14	177	*****	1.000	1.000	1.000	1.000	1.000	0.990	0.990	0.970	0.920
15	192	*****	1.000	1.000	0.990	1.000	1.000	0.990	0.990	0.950	0.890
16	207	*****	1.000	0.990	1.000	1.000	1.000	0.990	0.990	0.990	0.840

VARIABLE REACT TIME (s)

RUN

WORK SESSION	MIN	B1	B2	B3	B4	E	P.E.DAY1	P.E.DAY2	P.E.DAY	P.E.DAY4	P.E.DAY5
1	12	0.800	0.670	0.750	0.670	0.710	0.680	0.760	0.920	0.870	1.030
EXPOSURE 2	27	0.800	0.670	0.750	0.640	0.670	0.690	0.880	1.070	0.900	1.310
3	12	0.810	0.680	0.740	0.660	0.710	0.720	0.960	1.090	0.940	1.280
4	27	0.780	0.710	0.730	0.660	0.670	0.780	1.060	1.010	1.080	1.380
5	42	0.840	0.710	0.750	0.700	0.960	0.790	1.060	1.130	1.220	1.320
6	57	0.880	0.710	0.760	0.680	1.180	0.740	1.170	1.050	1.090	1.290
7	72	1.060	0.750	0.780	0.690	1.270	0.730	1.100	1.140	1.120	1.350
8	87	1.070	0.730	0.820	0.670	1.240	0.750	1.070	1.230	1.130	1.360
9	102	0.950	0.750	0.830	0.690	1.150	0.790	0.970	1.030	1.060	1.220
10	117	0.870	0.760	0.840	0.750	1.190	0.760	0.950	1.110	1.230	1.310
11	132	0.880	0.750	0.810	0.720	1.130	0.970	0.940	1.220	1.200	1.230
12	147	1.000	0.770	0.850	0.750	1.030	0.840	1.090	1.120	1.010	1.370
13	162	1.030	0.760	0.810	0.760	0.980	0.840	1.010	1.100	1.090	1.350
14	177	*****	0.700	0.850	0.720	0.990	0.670	1.030	1.160	1.050	1.300
15	192	*****	0.720	0.790	0.770	0.920	0.820	0.920	1.140	1.150	1.240
16	207	*****	0.730	0.820	0.730	0.900	0.840	0.990	1.020	1.040	1.350

EXPOSURE TO: 1100-RAD NEUTRON PULSE

SUBJECT 190 (2) VARIABLE ACCURACY

WORK SESSION	MIN	RUN B1	B2	B3	B4	E	P.E.DAY1	P.E.DAY2	P.E.DAY3	P.E.DAY4	P.E.DAY5
1	12	1.000	1.000	0.990	1.000	1.000	1.000	0.970	1.000	0.990	*****
2	27	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.320	*****
EXPOSURE 3	12	1.000	1.000	1.000	1.000	0.830	1.000	1.000	0.990	0.000	*****
4	27	1.000	1.000	1.000	1.000	0.970	1.000	1.000	1.000	0.000	*****
5	42	1.000	1.000	1.000	1.000	0.970	1.000	1.000	1.000	0.000	*****
6	57	1.000	1.000	1.000	0.990	0.990	1.000	0.990	1.000	0.000	*****
7	72	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	*****
8	87	1.000	1.000	1.000	1.000	1.000	1.000	0.990	1.000	0.000	*****
9	102	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.990	0.000	*****
10	117	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	*****
11	132	1.000	1.000	1.000	1.000	1.000	0.970	1.000	0.990	0.000	*****
12	147	1.000	1.000	1.000	0.980	1.000	0.910	0.990	0.990	0.000	*****
13	162	1.000	1.000	1.000	1.000	1.000	0.870	0.990	0.990	0.000	*****
14	177	*****	1.000	1.000	0.980	1.000	0.970	0.990	0.990	0.000	*****
15	192	*****	1.000	1.000	1.000	1.000	1.000	0.990	0.980	0.000	*****
16	207	*****	1.000	0.990	1.000	0.990	0.990	1.000	0.980	0.000	*****

VARIABLE REACT TIME (s)

WORK SESSION	MIN	RUN B1	B2	B3	B4	E	P.E.DAY1	P.E.DAY2	P.E.DAY3	P.E.DAY4	P.E.DAY5
1	12	0.610	0.530	0.690	0.560	0.530	0.500	0.700	0.950	1.120	*****
2	27	0.590	0.570	0.710	0.660	0.550	0.560	0.800	1.010	1.160	*****
EXPOSURE 3	12	0.680	0.620	0.820	0.600	0.650	0.590	0.860	0.960	0.000	*****
4	27	0.650	0.660	0.790	0.650	1.030	0.600	0.880	0.990	0.000	*****
5	42	0.660	0.650	0.760	0.650	0.860	0.640	0.910	1.010	0.000	*****
6	57	0.710	0.770	0.710	0.590	0.720	0.630	0.910	0.980	0.000	*****
7	72	0.700	0.710	0.800	0.650	0.780	0.690	0.920	0.950	0.000	*****
8	87	0.740	0.740	0.740	0.600	0.720	0.680	0.930	1.010	0.000	*****
9	102	0.740	0.670	0.700	0.580	0.720	0.730	0.940	1.110	0.000	*****
10	117	0.700	0.720	0.750	0.600	0.750	0.750	0.990	1.080	0.000	*****
11	132	0.760	0.720	0.740	0.560	0.790	0.850	0.990	1.050	0.000	*****
12	147	0.780	0.720	0.750	0.540	0.770	1.100	0.960	1.010	0.000	*****
13	162	0.810	0.770	0.740	0.600	0.750	1.300	0.960	1.040	0.000	*****
14	177	*****	0.710	0.780	0.540	0.760	0.800	1.000	1.170	0.000	*****
15	192	*****	0.760	0.760	0.580	0.830	0.860	0.990	1.110	0.000	*****
16	207	*****	0.720	0.730	0.580	0.800	0.850	1.000	1.180	0.000	*****

EXPOSURE TO: 1100-RAD NEUTRON PULSE

SUBJECT 318 (3) VARIABLE ACCURACY

WORK SESSION	MIN	RUN B1	B2	B3	B4	E	P.E.DAY1	P.E.DAY2	P.E.DAY3	P.E.DAY4	P.E.DAY5
1	12	1.000	1.000	1.000	1.000	1.000	1.000	0.980	1.000	1.000	0.990
EXPOSURE 2	27	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.990
3	12	0.990	1.000	1.000	1.000	0.760	1.000	1.000	1.000	0.990	0.970
4	27	0.990	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.990	0.970
5	42	0.990	1.000	1.000	1.000	0.220	1.000	1.000	0.990	1.000	0.720
6	57	0.990	1.000	1.000	1.000	0.620	1.000	1.000	1.000	0.990	0.030
7	72	0.980	1.000	1.000	1.000	0.620	1.000	1.000	0.980	0.990	0.010
8	87	0.980	1.000	1.000	1.000	0.810	1.000	1.000	0.990	0.990	*****
9	102	0.980	1.000	1.000	1.000	0.910	1.000	1.000	0.990	0.990	*****
10	117	0.970	0.990	0.990	1.000	0.980	1.000	0.990	0.990	0.990	*****
11	132	0.860	1.000	0.990	1.000	0.980	1.000	0.990	0.970	0.990	*****
12	147	0.840	1.000	1.000	1.000	0.980	1.000	0.990	0.970	0.990	*****
13	162	0.700	1.000	0.990	1.000	0.990	0.990	0.990	0.970	0.990	*****
14	177	*****	1.000	1.000	1.000	0.990	0.990	0.980	0.930	0.980	*****
15	192	*****	0.990	0.990	1.000	0.980	1.000	0.970	0.940	0.970	*****
16	207	*****	1.000	0.990	1.000	0.990	0.990	0.970	0.930	0.980	*****

VARIABLE REACT TIME (s)

WORK SESSION	MIN	RUN B1	B2	B3	B4	E	P.E.DAY1	P.E.DAY2	P.E.DAY3	P.E.DAY4	P.E.DAY5
1	12	0.830	0.760	0.830	0.720	0.750	0.750	0.820	1.010	1.030	1.170
EXPOSURE 2	27	0.840	0.820	0.840	0.700	0.730	0.740	0.860	0.980	1.090	1.260
3	12	0.800	0.780	0.850	0.730	0.710	0.740	0.920	1.030	1.090	1.230
4	27	0.770	0.770	0.860	0.800	0.910	0.800	0.970	1.010	1.080	1.230
5	42	0.800	0.820	0.880	0.760	0.910	0.760	1.000	1.070	1.090	1.020
6	57	0.830	0.840	0.840	0.760	1.260	0.740	1.000	1.070	1.020	0.500
7	72	0.740	0.790	0.830	0.780	1.280	0.780	1.050	1.070	1.100	1.500
8	87	0.750	0.780	0.810	0.770	1.210	0.780	1.000	1.160	1.130	*****
9	102	0.760	0.820	0.850	0.720	1.140	0.830	0.990	1.090	1.060	*****
10	117	0.800	0.840	0.830	0.770	1.110	0.720	1.020	1.040	1.030	*****
11	132	0.830	0.820	0.790	0.860	1.050	0.810	1.010	1.150	1.100	*****
12	147	0.880	0.770	0.810	0.770	1.050	0.850	1.070	1.160	1.090	*****
13	162	1.020	0.870	0.820	0.820	0.980	0.770	0.990	1.180	1.060	*****
14	177	*****	0.870	0.850	0.750	0.970	0.660	1.080	1.170	1.110	*****
15	192	*****	0.850	0.800	0.820	0.960	0.950	1.080	1.200	1.180	*****
16	207	*****	0.840	0.870	0.830	0.980	0.900	1.100	1.160	1.100	*****

EXPOSURE TO: 1100-RAD NEUTRON PULSE

SUBJECT 204 (4) VARIABLE ACCURACY

WORK SESSION	MIN	RUN B1	B2	B3	B4	E	P.E.DAY1	P.E.DAY2	P.E.DAY3	P.E.DAY4	P.E.DAY5
1	12	1.000	1.000	1.000	1.000	1.000	1.000	0.030	*****	*****	*****
2	27	1.000	1.000	1.000	1.000	1.000	1.000	0.000	*****	*****	*****
EXPOSURE 3	12	1.000	1.000	1.000	1.000	1.000	1.000	0.010	*****	*****	*****
4	27	1.000	1.000	1.000	1.000	0.980	1.000	0.010	*****	*****	*****
5	42	1.000	1.000	1.000	1.000	0.990	1.000	0.130	*****	*****	*****
6	57	1.000	1.000	1.000	1.000	0.950	1.000	0.020	*****	*****	*****
7	72	1.000	1.000	1.000	1.000	0.990	1.000	0.030	*****	*****	*****
8	87	1.000	1.000	1.000	1.000	1.000	1.000	0.010	*****	*****	*****
9	102	1.000	1.000	1.000	1.000	1.000	1.000	0.010	*****	*****	*****
10	117	1.000	1.000	1.000	1.000	1.000	1.000	0.020	*****	*****	*****
11	132	1.000	1.000	1.000	1.000	1.000	0.990	0.000	*****	*****	*****
12	147	1.000	1.000	1.000	1.000	1.000	1.000	0.000	*****	*****	*****
13	162	1.000	1.000	1.000	1.000	0.990	0.980	0.000	*****	*****	*****
14	177	*****	1.000	1.000	1.000	1.000	0.980	0.000	*****	*****	*****
15	192	*****	1.000	1.000	1.000	1.000	0.980	0.000	*****	*****	*****
16	207	*****	1.000	1.000	1.000	1.000	0.990	0.000	*****	*****	*****

VARIABLE REACT TIME (s)

WORK SESSION	MIN	RUN B1	B2	B3	B4	E	P.E.DAY1	P.E.DAY2	P.E.DAY3	P.E.DAY4	P.E.DAY5
1	12	0.670	0.660	0.590	0.600	0.610	0.620	0.620	*****	*****	*****
2	27	0.720	0.650	0.580	0.580	0.610	0.690	0.500	*****	*****	*****
EXPOSURE 3	12	0.680	0.640	0.600	0.610	0.640	0.680	1.500	*****	*****	*****
4	27	0.670	0.620	0.630	0.620	0.770	0.640	0.600	*****	*****	*****
5	42	0.690	0.620	0.610	0.600	0.830	0.630	1.040	*****	*****	*****
6	57	0.680	0.630	0.600	0.620	0.980	0.640	1.000	*****	*****	*****
7	72	0.730	0.640	0.610	0.630	0.800	0.620	0.830	*****	*****	*****
8	87	0.760	0.640	0.620	0.650	0.700	0.620	1.000	*****	*****	*****
9	102	0.700	0.660	0.600	0.660	0.650	0.640	0.600	*****	*****	*****
10	117	0.690	0.680	0.590	0.640	0.690	0.660	1.000	*****	*****	*****
11	132	0.730	0.690	0.630	0.690	0.660	0.660	2.000	*****	*****	*****
12	147	0.710	0.720	0.660	0.670	0.700	0.680	0.000	*****	*****	*****
13	162	0.750	0.720	0.640	0.670	0.640	0.700	0.000	*****	*****	*****
14	177	*****	0.720	0.650	0.650	0.680	0.580	0.000	*****	*****	*****
15	192	*****	0.710	0.650	0.640	0.710	0.770	0.000	*****	*****	*****
16	207	*****	0.700	0.700	0.650	0.730	0.800	0.000	*****	*****	*****

EXPOSURE TO: 1100-RAD NEUTRON PULSE

SUBJECT 356 (5) VARIABLE ACCURACY

WORK SESSION	MIN	RUN B1	B2	B3	B4	E	P.E.DAY1	P.E.DAY2	P.E.DAY3	P.E.DAY4	P.E.DAY5
1	12	0.990	0.990	0.990	1.000	1.000	1.000	0.990	0.990	0.990	0.990
EXPOSURE 2	27	1.000	1.000	0.980	1.000	1.000	0.990	0.990	0.990	0.990	0.980
3	12	0.990	0.990	0.990	1.000	0.970	0.990	0.980	0.980	1.000	0.990
4	27	0.990	0.990	1.000	1.000	1.000	0.990	0.990	0.980	1.000	0.980
5	42	0.980	0.990	1.000	1.000	0.960	0.990	0.980	0.980	1.000	0.940
6	57	0.990	0.990	1.000	1.000	0.950	0.990	0.980	0.970	1.000	0.980
7	72	0.990	0.990	1.000	1.000	0.920	0.990	0.980	0.980	0.990	0.970
8	87	0.990	0.990	1.000	0.990	0.880	0.990	0.960	0.980	0.990	0.930
9	102	0.990	0.990	1.000	1.000	0.940	1.000	0.980	0.970	0.980	0.960
10	117	0.980	1.000	1.000	1.000	0.940	0.990	0.970	0.970	0.980	0.920
11	132	0.980	0.990	1.000	1.000	0.950	0.990	0.980	0.960	0.990	0.920
12	147	0.990	1.000	0.990	1.000	0.960	0.980	0.960	0.950	0.990	0.930
13	162	1.000	0.980	1.000	1.000	0.940	0.980	0.970	0.990	0.990	0.910
14	177	*****	0.990	1.000	1.000	0.920	0.980	0.960	0.950	0.970	0.890
15	192	*****	0.990	0.990	1.000	0.890	0.990	0.970	0.950	0.990	0.920
16	207	*****	0.990	1.000	0.990	0.820	0.980	0.960	0.950	0.980	0.940

VARIABLE REACT TIME (s)

WORK SESSION	MIN	RUN B1	B2	B3	B4	E	P.E.DAY1	P.E.DAY2	P.E.DAY3	P.E.DAY4	P.E.DAY5
1	12	0.850	0.970	0.970	0.780	0.710	0.750	0.950	1.040	0.870	1.060
EXPOSURE 2	27	1.090	1.040	0.980	0.740	0.720	0.900	1.040	1.180	0.960	1.230
3	12	1.150	1.000	0.770	0.750	0.850	0.820	1.070	1.210	0.970	1.230
4	27	1.190	0.960	0.820	0.810	0.810	0.900	1.120	1.210	0.960	1.270
5	42	1.180	0.980	0.910	0.840	0.990	0.950	1.120	1.250	1.020	1.310
6	57	1.170	0.980	0.910	0.790	1.010	0.960	1.190	1.190	1.120	1.300
7	72	1.150	1.110	0.930	0.830	1.190	0.900	1.180	1.190	1.130	1.230
8	87	1.210	0.980	0.950	0.[illegible]	1.280	0.910	1.160	1.200	1.090	1.380
9	102	1.270	1.040	0.960	0.750	1.350	0.940	1.150	1.150	1.230	1.320
10	117	1.290	0.960	0.940	0.750	1.330	0.970	1.210	1.180	1.180	1.350
11	132	1.240	1.040	0.940	0.780	1.310	1.000	1.180	1.220	1.200	1.400
12	147	1.250	1.010	0.900	0.810	1.240	1.050	1.180	1.220	1.150	1.330
13	162	1.230	0.990	0.960	0.810	1.230	1.020	1.220	1.120	1.230	1.280
14	177	*****	1.020	0.960	0.840	1.210	1.020	1.180	1.180	1.240	1.390
15	192	*****	1.050	0.970	0.880	1.200	1.050	1.230	1.200	1.290	1.350
16	207	*****	1.050	0.970	0.830	1.240	1.030	1.170	1.260	1.250	1.320

EXPOSURE TO 1100-RAD NEUTRON PULSE

SUBJECT 348 (G) VARIABLE ACCURACY

WORK SESSION	MIN	RUN B1	B2	B3	B4	E	P.E.DAY1	P.E.DAY2	P.E.DAY3	P.E.DAY4	P.E.DAY5
1	12	0.980	1.000	1.000	0.990	1.000	1.000	1.000	1.000	1.000	0.970
EXPOSURE 2	27	0.990	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.600
3	12	0.990	0.980	0.990	1.000	1.000	1.000	1.000	1.000	1.000	0.970
4	27	0.990	1.000	0.990	0.980	1.000	1.000	1.000	0.990	0.990	0.970
5	42	0.990	1.000	1.000	0.990	0.990	1.000	1.000	0.990	0.990	0.930
6	57	0.990	1.000	0.990	0.980	0.980	1.000	1.000	0.980	1.000	0.910
7	72	0.990	0.980	0.990	0.990	0.750	1.000	1.000	0.990	1.000	0.890
8	87	1.000	0.990	0.990	0.990	0.750	1.000	1.000	1.000	0.990	0.850
9	102	0.990	0.990	0.990	0.990	0.910	1.000	1.000	1.000	1.000	0.920
10	117	0.990	0.990	0.990	0.990	0.410	1.000	1.000	0.990	1.000	0.910
11	132	0.990	0.990	1.000	1.000	0.000	1.000	1.000	1.000	1.000	0.950
12	147	0.990	0.990	0.990	1.000	0.000	1.000	1.000	0.990	0.990	0.900
13	162	1.000	0.990	0.990	1.000	0.020	1.000	1.000	1.000	0.990	0.920
14	177	*****	0.990	0.990	1.000	0.830	1.000	1.000	1.000	1.000	0.930
15	192	*****	0.990	1.000	1.000	0.990	1.000	1.000	0.990	0.990	0.910
16	207	*****	0.990	1.000	1.000	0.990	1.000	1.000	1.000	0.990	0.910

VARIABLE REACT TIME (S)

WORK SESSION	MIN	RUN B1	B2	B3	B4	E	P.E.DAY1	P.E.DAY2	P.E.DAY3	P.E.DAY4	P.E.DAY5
1	12	0.630	0.780	0.700	0.650	0.530	0.640	0.710	0.780	0.890	1.100
EXPOSURE 2	27	0.780	0.760	0.790	0.670	0.550	0.680	0.750	0.760	0.900	1.230
3	12	0.720	0.740	0.800	0.730	0.590	0.730	0.720	0.800	0.980	1.070
4	27	0.750	0.690	0.840	0.520	0.710	0.700	0.770	0.900	0.920	1.080
5	42	0.810	0.760	0.760	0.490	0.730	0.750	0.790	0.960	0.900	1.180
6	57	0.810	0.810	0.870	0.470	0.950	0.750	0.740	1.000	0.920	1.220
7	72	0.900	0.860	0.850	0.480	1.100	0.770	0.790	0.890	0.870	1.290
8	87	0.850	0.850	0.890	0.480	0.960	0.770	0.760	0.940	0.880	1.270
9	102	0.830	0.870	0.920	0.480	1.030	0.870	0.810	0.890	0.870	1.280
10	117	0.890	0.830	0.910	0.480	1.070	0.780	0.890	0.890	0.900	1.260
11	132	0.850	0.820	0.870	0.540	0.000	0.740	0.810	0.860	0.930	1.250
12	147	0.890	0.910	0.860	0.630	0.000	0.770	0.850	0.900	0.930	1.230
13	162	0.790	0.900	0.900	0.650	1.500	0.840	0.790	0.840	0.950	1.210
14	177	*****	0.900	0.840	0.720	0.980	0.870	0.790	0.860	1.010	1.260
15	192	*****	0.910	0.840	0.690	0.930	0.790	0.810	0.880	0.970	1.290
16	207	*****	0.900	0.900	0.730	0.940	0.820	0.890	0.890	0.990	1.250

EXPOSURE TO: 1100-RAD NEUTRON PULSE

SUBJECT 344 (7) VARIABLE ACCURACY

WORK SESSION	MIN	B1	B2	B3	B4	RUN E	P.E.DAY1	P.E.DAY2	P.E.DAY3	P.E.DAY4	P.E.DAY5
1	12	0.990	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.990	*****
2	27	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.990	*****
EXPOSURE 3	12	1.000	1.000	1.000	1.000	0.800	1.000	1.000	1.000	0.980	*****
4	27	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.990	*****
5	42	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.990	*****
6	57	1.000	1.000	1.000	1.000	0.980	1.000	1.000	0.990	0.980	*****
7	72	1.000	1.000	1.000	1.000	0.990	0.990	1.000	0.980	0.980	*****
8	87	1.000	1.000	1.000	1.000	0.980	1.000	1.000	0.990	0.940	*****
9	102	1.000	1.000	1.000	1.000	0.990	1.000	1.000	1.000	0.950	*****
10	117	1.000	1.000	1.000	1.000	0.980	0.990	0.990	1.000	0.860	*****
11	132	1.000	1.000	1.000	1.000	0.980	1.000	0.990	1.000	0.870	*****
12	147	0.990	1.000	1.000	1.000	0.990	1.000	0.990	0.990	0.640	*****
13	162	1.000	1.000	0.990	1.000	0.990	1.000	0.990	0.990	0.350	*****
14	177	*****	1.000	1.000	1.000	0.990	1.000	0.990	1.000	0.000	*****
15	192	*****	1.000	1.000	1.000	0.990	1.000	0.990	1.000	0.000	*****
16	207	*****	1.000	1.000	1.000	0.980	1.000	0.990	0.990	0.000	*****

VARIABLE REACT TIME (s)

WORK SESSION	MIN	B1	B2	B3	B4	RUN E	P.E.DAY1	P.E.DAY2	P.E.DAY3	P.E.DAY4	P.E.DAY5
1	12	0.910	0.690	0.670	0.790	0.710	0.780	0.790	0.860	0.830	*****
2	27	0.870	0.690	0.670	0.720	0.690	0.860	0.870	0.860	0.870	*****
EXPOSURE 3	12	0.830	0.730	0.680	0.720	0.760	0.780	0.920	0.900	0.870	*****
4	27	0.800	0.730	0.690	0.730	0.800	0.720	1.010	0.920	0.860	*****
5	42	0.760	0.720	0.710	0.720	0.870	0.780	0.960	0.930	0.910	*****
6	57	0.770	0.770	0.750	0.720	0.850	0.850	0.950	0.950	0.900	*****
7	72	0.820	0.730	0.760	0.710	0.950	0.940	0.960	0.930	0.930	*****
8	87	0.850	0.720	0.810	0.740	1.040	1.000	1.040	0.920	1.010	*****
9	102	0.870	0.740	0.830	0.780	0.980	0.820	0.990	0.940	0.960	*****
10	117	0.820	0.760	0.760	0.780	0.960	0.890	1.030	0.880	1.150	*****
11	132	0.860	0.800	0.750	0.800	1.030	0.930	0.990	0.910	1.310	*****
12	147	0.880	0.720	0.790	0.780	1.020	0.980	0.920	0.930	1.130	*****
13	162	0.800	0.750	0.750	0.810	0.970	0.970	1.000	0.920	1.230	*****
14	177	*****	0.760	0.700	0.790	0.990	0.960	1.000	0.950	0.000	*****
15	192	*****	0.740	0.710	0.790	1.030	0.870	1.020	0.940	0.000	*****
16	207	*****	0.760	0.720	0.760	1.030	0.900	1.180	0.900	0.000	*****

EXPOSURE TO: 1100-RAD NEUTRON PULSE

SUBJECT 346 (8) VARIABLE ACCURACY

WORK SESSION	MIN	B1	B2	B3	B4	E	P.E.DAY1	P.E.DAY2	P.E.DAY3	P.E.DAY4	P.E.DAY5
					RUN						
1	12	1.000	1.000	1.000	0.990	1.000	1.000	*****	*****	*****	*****
2	27	1.000	1.000	1.000	1.000	1.000	1.000	*****	*****	*****	*****
EXPOSURE											
3	12	1.000	1.000	1.000	1.000	1.000	1.000	*****	*****	*****	*****
4	27	1.000	1.000	1.000	1.000	1.000	1.000	*****	*****	*****	*****
5	42	1.000	1.000	1.000	1.000	1.000	1.000	*****	*****	*****	*****
6	57	1.000	1.000	1.000	1.000	0.990	1.000	*****	*****	*****	*****
7	72	1.000	1.000	1.000	1.000	1.000	1.000	*****	*****	*****	*****
8	87	1.000	1.000	1.000	1.000	0.990	1.000	*****	*****	*****	*****
9	102	1.000	1.000	1.000	1.000	0.990	1.000	*****	*****	*****	*****
10	117	1.000	1.000	1.000	1.000	0.970	1.000	*****	*****	*****	*****
11	132	1.000	1.000	1.000	1.000	0.990	1.000	*****	*****	*****	*****
12	147	1.000	1.000	1.000	1.000	0.990	1.000	*****	*****	*****	*****
13	162	1.000	1.000	1.000	1.000	0.990	1.000	*****	*****	*****	*****
14	177	*****	1.000	1.000	1.000	1.000	1.000	*****	*****	*****	*****
15	192	*****	1.000	1.000	1.000	0.690	1.000	*****	*****	*****	*****
16	207	*****	1.000	1.000	1.000	0.000	0.990	*****	*****	*****	*****

VARIABLE REACT TIME (s)

WORK SESSION	MIN	B1	B2	B3	B4	E	P.E.DAY1	P.E.DAY2	P.E.DAY3	P.E.DAY4	P.E.DAY5
					RUN						
1	12	0.710	0.520	0.560	0.590	0.570	0.630	*****	*****	*****	*****
2	27	0.670	0.590	0.570	0.560	0.540	0.580	*****	*****	*****	*****
EXPOSURE											
3	12	0.690	0.560	0.560	0.570	0.610	0.620	*****	*****	*****	*****
4	27	0.660	0.560	0.570	0.580	0.650	0.630	*****	*****	*****	*****
5	42	0.570	0.590	0.560	0.580	0.610	0.610	*****	*****	*****	*****
6	57	0.590	0.560	0.590	0.580	0.680	0.600	*****	*****	*****	*****
7	72	0.590	0.560	0.590	0.590	0.720	0.610	*****	*****	*****	*****
8	87	0.560	0.570	0.580	0.590	0.660	0.700	*****	*****	*****	*****
9	102	0.550	0.560	0.580	0.610	0.590	0.670	*****	*****	*****	*****
10	117	0.560	0.570	0.580	0.600	0.610	0.700	*****	*****	*****	*****
11	132	0.570	0.560	0.600	0.640	0.630	0.690	*****	*****	*****	*****
12	147	0.580	0.590	0.580	0.670	0.550	0.700	*****	*****	*****	*****
13	162	0.640	0.580	0.600	0.640	0.550	0.670	*****	*****	*****	*****
14	177	*****	0.580	0.600	0.650	0.550	0.660	*****	*****	*****	*****
15	192	*****	0.600	0.600	0.630	0.650	0.700	*****	*****	*****	*****
16	207	*****	0.600	0.630	0.620	0.000	0.710	*****	*****	*****	*****

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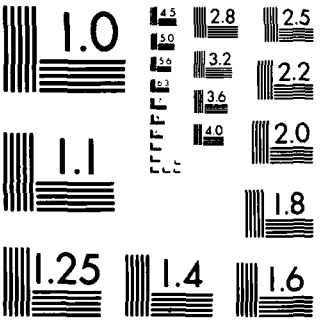

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